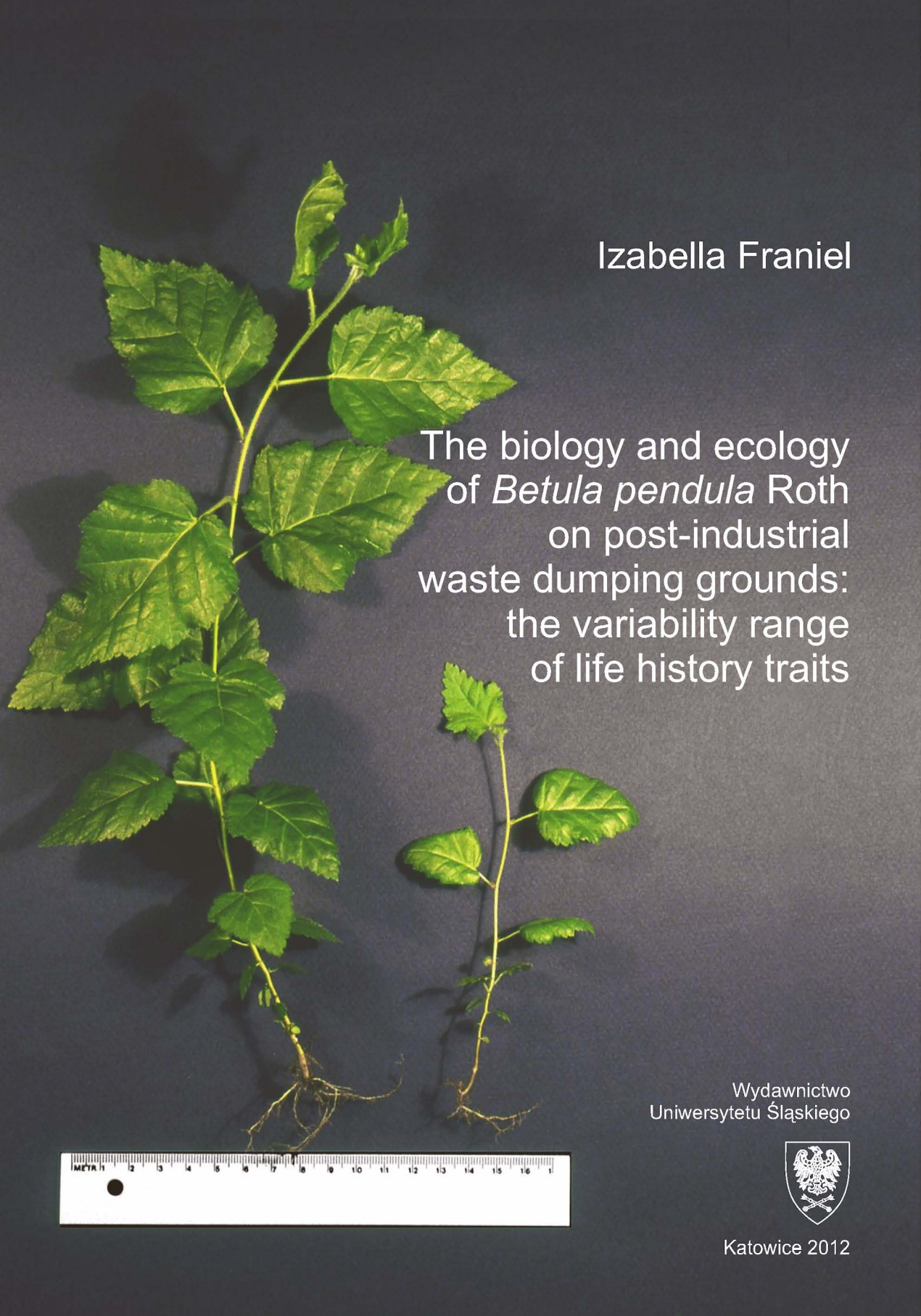

Izabella Franiel

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Wydawnictwo
Uniwersytetu Śląskiego

Katowice 2012

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Any knowledge gained on earth
means nothing compared to
a kind word and look of your parents
Andrzej Stanisz

NR 2980

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Part One

Theoretical overview

Introduction and the research objectives

The ability of an organism to reproduce ensures the sustainable species existence. A life cycle of specimens forming a population is determined, to a certain extent, by genetic factors. A genetic program, however, includes a broad scale of possible development routes, and the one ultimately followed depends, to a large extent, on conditions in which a given specimen develops (Andrzejewski, Falińska 1986; Falińska 1990). The survival and the development of an organism are conditioned both by abiotic and population factors. The extent of satisfaction by the environment of life requirements of individuals determines their growth rate, and also the efficiency of reproduction.

The efficiency of propagation is affected mainly by individual fertility, as well as by progeny viability until the reproductive stage (Rabotnow 1985; Seidling, Starfinger, Stocklin 1994). The survival of individuals and their reproductive success is a consequence of species biological traits modified by natural selection, as well as miscellaneous adaptation strategies (Falińska 1977). Some populations respond to deteriorating life conditions with increased reproduction capacity. However, after exceeding a certain level of threat, reproduction does not take place at all (Fitter, Hay 1991; Kőrner 2003).

A species is not a stable being and undergoes constant irregular changes. It is not possible to study a biological cross-section of the whole species, so usually only fragments of populations are studied. These populations are dynamic sets of individuals and the changes in variation of their morphological and genetic features are the essence of the evolutionary changes (Grodziński, Weiner, Maycock 1984; Lorek 1993). Individuals are characterised by a certain number of constant features

and features which vary within certain limits. Crossing these limits may lead to speciation (Valladares, Gianoli, Gomez 2007).

The European white birch is a habitat-forming species with a broad ecological scale, resistant to environmental pollution. These traits are all the more valuable, because within industrial districts there are considerable areas of post-industrial wastelands, and birch is a suitable species for their afforestation. A thorough knowledge of the developmental biology of a *Betula pendula* Roth population and its response to variable environmental conditions can provide practical bases for introducing this species in the areas affected by long-lasting anthropopressure.

The process of vegetation development in open post-industrial wastelands is still hardly explored. It is worthwhile to examine the spatial variability of vegetation encroaching on these areas, as well as to what extent the life conditions and individual traits are reflected in their spatial organization. Spatial organization of plant populations is one very interesting, although obviously difficult ecological issues. The problem consists in investigating the causes behind the formation of specific spatial structures and consequences of different ways of spatial occupation by specimens faced by a population and its surroundings (Bergon, Mortimer, Thompson 1999; Falińska 2002). Still, the precise determination of the spatial structure type must be a prerequisite for this kind of research. The distribution of plants is determined by a possibility of their growth and development, as well as by many habitat factors and interactions between specimens of their own and other species (Bergon, Mortimer 1981; Krebs 2011).

When analysing the phenomenon of spatial variability of plants, particular attention was paid to influence exerted by different abiotic factors. The following factors were usually taken into account: water, light and soil properties, and thus factors that determine the increase and the development of plants (Bolibok 2002). Together with the development of plant ecology, there were attempts to consider several factors in ecological processes altogether. When trying to model these relationships, large gaps were revealed and inability to determine the results of their total influence, which in turn does not permit generalization of these relationships.

Comprehensive research on spatial variability of plants and taking into account several variables in one analysis, is now possible due to adaptation of the geostatistical method for spatial analysis of data variability. For better comprehension and understanding of the spatial structure of *B. pendula* in this study, apart from classical statistics, also a new method describing the variability — geostatistics — was applied. Geostatistical tools provide a possibility to describe spatial variability of the studied variables by means of a few, easily interpretable parameters — *sill*, *nugget*, *range* (Kapusta 2004). It provides an opportunity for comparison of the spatial structure of many variables within one research plot and single variables between different plots.

The results of the presented study can constitute a new source of knowledge about the development of vegetation cover, which encroaches on degraded areas of post-industrial wastelands.

The following research hypotheses were defined.

Populations of silver birch growing on post-industrial waste dumping grounds represent different morphotypes compared to birch populations growing in semi-natural habitats.

There are differences in fecundity, the condition of seeds (e.g. germination capacity and energy) of birch trees growing on dumping grounds compared to trees in semi-natural habitats.

Seedlings developing from seeds coming from heaps are more important in the restoration of dumps than seedlings coming from semi-natural populations.

The research aimed at evaluating the characteristics of *Betula pendula* populations growing in conditions of diversified anthropopressure through:

1. Selected life history traits:
   — parameters of the size and biomass of specimens
   — evaluation of specimens' fertility
   — reproduction efficiency
2. Determination of the condition of birch specimens:
   — including selected stress indicators in the research (e.g. the content of chlorophyll)
3. Evaluation of abiotic and biotic factors responsible for the spatial distribution of seedlings.

The results of long-term researches on settlement processes by particular species in post-industrial dumping grounds may facilitate planning works related to restoration and development of such areas (Bradshaw 1989; Rostański 2006).

Adaptation as an expression of adjustment by a species to environmental conditions

In the nature, environmental factors, both biotic and abiotic ones, do not influence organisms individually, and the relationships between them are very complicated. The fact that life processes of plants are influenced by numerous and changeable environmental factors, testifies to relatively broad limits of their tolerance (Barcikowski 1994; Green 1994; Kocjan 1994). Nevertheless, these limits do exist. If a factor reaches extreme values, then an organism loses its viability and is exposed to injuries, and may even vanish. Potentially, all environmental factors may exert some influence on a plant. In fact, not all of them are equally important in relation to a specific phenomenon, not all of them participate in it. Each of them becomes crucially important when its value is approaching the tolerance limits of a given organism (Daubenmire 1973; Falińska 1996). It is worthwhile to emphasize that minimum, maximum and optimal values are not constant, but change under the influence of other factors affecting a plant. In this tremendous game of changeable life conditions, there is yet another very important element, i.e. requirements of a plant, which are not stable and change in different stages of its

development. And, at the same time, this frequently applies to requirements in relation to basic habitat conditions, such as heat, light, moisture (Daubenmire 1973; Freedman 1995; Falińska 1996; Bloor 2003).

Each organism has a specific ecological system, a set of characteristics and traits, which affect its ecological requirements and enable it to occupy a certain habitat. These are properties of external and internal structure, metabolism and method of nutrition, the development rhythm, biology of propagation and many other characteristics (Safford 1990). And thus, the ecological structure of a given species determines which ecological conditions must prevail in a given place for a species to occur. If species traits match these conditions, we say that a species is adapted to a given environment. Particular traits of a species, both physiological, morphological and anatomical, matching specific habitat conditions are usually called the adaptation. The large number of these adaptations, their diversity and functionality in responding to external conditions is amazing. The basis for their development is the variation of organisms. There are three types of adaptations: modulatory, modificatory and evolutionary (Bergon, Mortimer 1981; Begon, Harper, Townsend 1990; Podbielkowski, Podbielkowska 1992; Yamashita et al. 2000).

Modulatory adaptations develop under the influence of brief changes in external conditions and proceed very quickly, and at the same time are short-lived and reversible. They usually occur at the biochemical and physiological level, and seldom are combined with discernible morphological changes. The strength of an organism's response usually depends on the development stage of an individual (Barcikowski 1994).

Modificatory adaptations take place during the ontogenesis (ontogeny) of an organism and function for a long time in periods important for the life of a given specimen. They constitute a positive response of a given organism to specific habitat conditions in the defined limits of their influence. Since they have a form of morphological changes, permanent in the life of a specimen, and are induced by biochemical processes of this specimen, these adaptations are not inherited (Begon, Harper, Townsend 1990; Podbielkowski, Podbielkowska 1992; Bergon, Mortimer, Thompson 1999).

Evolutionary adaptations resulting from random mutations, preserved through natural selection, are inherited adaptations. Inherited traits, specific for every taxon, determine its ecological structure and define optimal requirements in relation to environmental conditions (Duarte et al. 1995).

Responses of plants to stress-related factors

The definition of stress

According to Levitt, stress is any environmental factor capable of inducing a potentially harmful physical or chemical change (strain) in a plant (Levitt 1980).

This definition, despite its universal applicability, provides numerous interpretation difficulties.

It is not clear to what extent the stress should be interpreted only as having the capability of inducing the changes in the response of a plant, or to what extent as a factor actually inducing a given change. Thus it is not known whether this kind of change is possible only potentially, or is it a necessary effect of stress.

Another difficulty in understanding the notion of stress results from the fact that it is not always possible to define precisely what is optimal for plants. This difficulty is related to the second part of the Levitt's definition, which says that a change (strain) induced by stress is potentially harmful for plants. It is questionable whether a change resulting from the stress causes only adverse effects or also adaptation effects, conducive to adaptation for environmental conditions. Several observed changes do not have explicitly harmful or adaptive nature.

Yet another issue within the meaning of the concept of stress is the fact that stress-related factors usually do not occur alone, and numerous interactions between them are normal phenomena (Etherington 1988; Barnes et al. 2007).

Moreover, stress can exert clearly diverse influence depending on particular phases of a plant's life cycle. Complexity of an organism's response to stress results in the fact that separation of stress from its effect in terms of a cause and an effect is often very difficult or even impossible (Woźny 1995; Wójcik, Tukendorf 1995).

In the discussion of plants' responses to stress, also the word adaptation often appears. It is used in two concepts: in relation to the significance of a given trait for the survival in the environment (fitness) and in relation to the evolutionary origin of a given trait. The latter meaning assumes that the process of adaptation consists in the inheritance of a structural or functional modification.

One could say that the adaptation to the environment is conditioned by having an optimal combination of traits by a given organism, which minimizes the adverse influence and maximizes the positive impacts of the environment.

Strategies of plants' responses to stress

According to Levitt, the tolerance of plants to stress might be manifested in two strategies: escape (escape stress) and resistance to stress (resist stress) (Woźny 1995). The former consists in the development of physical or chemical barriers reducing the probability of access of a stress factor to cells of an organism and inducing the injuries. This strategy is implemented when the intensity of a stress factor fluctuates with certain cyclicity, and the active stage of a plant's life cycle coincides with a development period most favourable for a plant. Ephemeral plants could be an example, for which periodic water deficiency is a stress factor. In another case, a plant can avoid any contact with a stress factor through a mechanism consisting in its ability to modify a habitat (Owen 1990).

According to Levitt, within the second strategy, we should distinguish the avoidance of an adverse physical or chemical change caused by stress (stress avoidance) and the tolerance towards the stress affecting a plant (stress tolerance), (Levitt 1980). In its avoidance of a stress-induced change, a plant do not reveal any

morphological and physiological effects of stress, despite the fact that in a physical sense the stress did occur. In another case, normal biological activity of a plant is disturbed, but it preserves the capability to grow further in the conditions of stress, and it maintains the homeostasis. In the strategy of stress tolerance by a plant, its response is determined by internal concentration of a stress factor and by a biochemical threshold of tolerance to this factor. If internal concentration exceeds the threshold value, an organism gets injured (Fitter, Hay 1991; Woźny 1995). Structural and functional components of plants, for instance particular organs, tissues and cells, may differ in their thresholds for biochemical tolerance. Therefore, the same stress factor, with the same intensity, can induce different physical or chemical changes depending on the affected level of organization. It can happen, however, that plants will demonstrate a similar level of biochemical tolerance, and consequently will experience the same stress influence. A possible difference in the tolerance ranges between these plants can be caused by different reparation mechanisms, incommensurable with each other, which ensure the survival (Etherington 1988; Fitter, Hay 1991; Wójcik, Tukendorf 1995).

The concept of Grime life-history strategies

A set of evolutionary developed traits, which enable the existence and reproduction in a specific environment, is called a life strategy of a species (Faliński, Pawlaczyk 1990; Faliński, Pawlaczyk 1993, Brzeziecki 2000). The basic premise in the theory of strategy is the belief that habitats exert selective influence on plants. The second important premise assumes that adaptation capabilities of an organism are limited in such a way that adaptation to one of the existence types and a given habitat is connected with genetic characteristics, which exclude the possibility of succeeding in different conditions (Faliński, Pawlaczyk 1991).

One of the variants of the theory on plants' strategies is a model by Grime, where three mechanisms: competition, stress and disturbance are main determinants of plants' development (Grime 1979; Grime 1992; Czarnecka 1995; Grime 2001). The essence of competitive interactions is the tendency of neighbouring plants to exploit the same environmental resources. Whereas stress is connected with external influence of the environment and it reduces entirely or partially the production of plant biomass, the disturbance is a mechanism inducing a partial or overall elimination of plants. These three identified basic mechanisms are related to habitat conditions, defined by sustainability and productivity of a given habitat. Grime distinguished plants specialized towards competition, resistance to stress and ruderal plants (Grime 1977; Grime 1979; Grime 1986; Pirożnikow 1996).

In undisturbed habitats characterized by high productivity, plants with strong competitive abilities predominate. They are characterized by rapid growth and colonization of a given area, as well as high efficiency in exploiting the environmental resources. Large accumulation of biomass leads to depletion of nutrients within a short time. Plants respond to changes in the environment conditions phenotypically, without developing any special physiological or biochemical mechanisms to live in the conditions of stress. These plants do not have

a soil seed bank either, and their count is controlled by the mortality rate of specimens at the seedling and juvenile stage (Grime 1979; Falińska 1996).

In stable habitat conditions, together with constant deficiency of mineral substances, plants resistant to stress begin to occur. Their leaves and roots function for many years, and processes of nutrients uptake and growth are separated from each other and are connected with climatic conditions. A replacement of plant parts proceeds slowly, and differentiating cells constitute a small part of biomass. These plants have the ability of efficient, economical management of limited habitat resources and their complete exploitation. Morphological adaptation is the dominant form of response to stress, which consists in rapid functional changes of tissues, as well as the development of specific physiological mechanisms to increase the efficiency of life processes (Grime 1979; Bergon, Harper, Townsend 1990).

On the other hand, in productive but disturbed habitats, ruderal plants begin to occur. They are characterized by intensive biomass growth and high seed production, often increased by vegetative reproduction. Seeds are transported by wind but stay dormant in the soil in the form of a seed bank. Having a low competitive capability, they are able to occupy sites not colonized by other plants within a short time. In many plants with this type of strategy, a response to environmental stress consists in very early induction of flowering, whereas allocation of a large part of the biomass coincides with reproductive processes, even in the conditions of extreme growth inhibition and early mortality (Falińska 1998; Poorter et al. 2009).

Spatial organization of populations

Spatial variability of the natural environment is a natural and inevitable environmental feature. Each element of this environment is characterized by its own variation and at the same time, each of them affects a different element of this environment (Usowicz, Usowicz 2004). One of the elements of the natural environment, which has long raised considerable interest among ecologists, is the spatial structure of plant and animal populations (Bolibok 2002; Andrzejewski, Falińska 1986). In order to increase the knowledge and understanding of the spatial structure, it is necessary to identify the causes leading to a given variation (Usowicz 1999).

There are different causes of the development of a given spatial structure. To a large extent, it depends on biological properties of species, diversification of life conditions of populations, as well as interactions between specimens of their own and other species. The following question still remains open: is the repeatability of a spatial population distribution pattern related to a specific habitat type, or is it characteristic of species with specific biological properties (Kreebs 1996). The range of these problems has been explored in different ways. Based on the researches to date, it was found that populations of the same species in different conditions differ

in spatial patterns (Falińska 1996). Quite often, specimens of the same species in different places of a population's home range can be scattered or form clumps of different size and stability. The current knowledge of ecologists allows a statement that many spatial patterns of populations of a given species can be observed within one habitat, but also often — just one spatial pattern among many plant species (Falińska 1996).

Falińska (2002) reports that spatial structure is dynamic and changes in the distribution of specimens are associated with both subsequent phases of the population development, as well as with seasonal and long-term variability in life conditions or also with other transformations of the environment.

Types of spatial structure

As stated above, the distribution of specimens in natural populations depends on many simultaneously operating factors, both intrapopulational and environmental ones (Szwagrzyk, Ptak 1991). Therefore, most often a complex spatial structure of plant populations develops.

In natural conditions, a variety of the distribution of specimens is far from classic models of spatial structure (random, uniform or even, aggregated or clumped). Odum (1977) proposes five types. He distinguishes the following types of

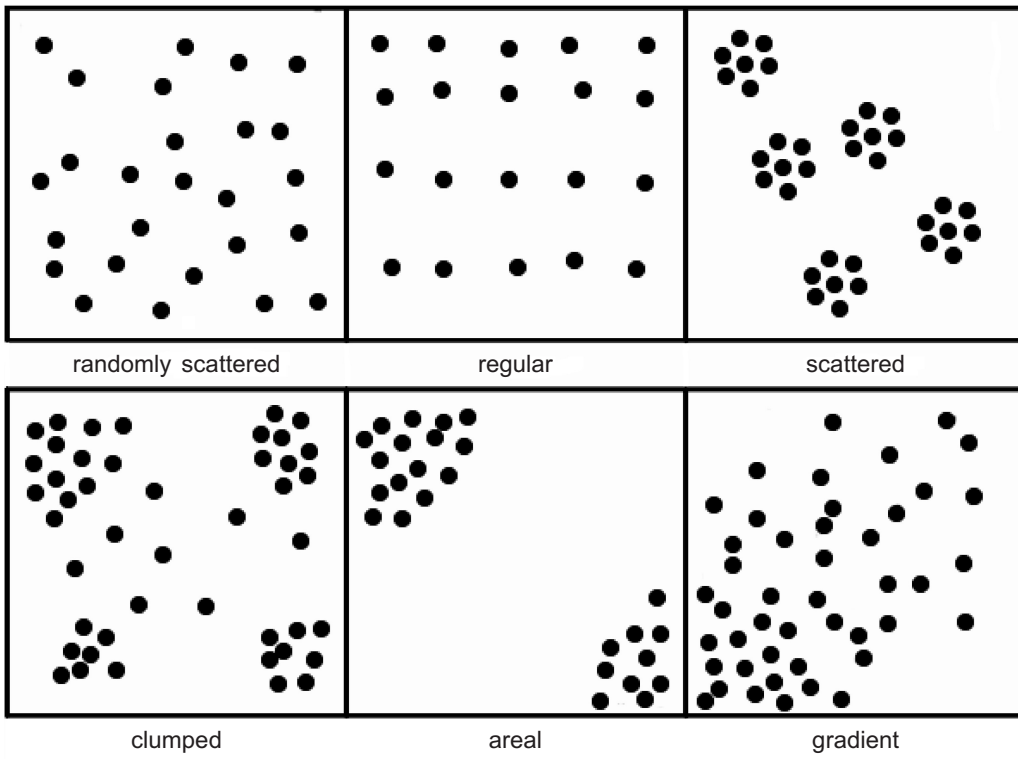


Fig. 1. Types of spatial distribution of plant populations (Falińska 1996 — altered)

structure: (1) random, (2) uniform or even, (3) randomly clumped, (4) evenly clumped, (5) clumped in clusters, whereas Falińska (1996) proposes the following six types of structure: (1) random, (2) regular, (3) tussocky, (4) clumped, (5) areal, (6) gradient (Fig. 1).

The most frequently encountered type of spatial distribution of specimens is the one where presence of two or three elements is necessary for a precise description of population structure. Falińska (1996) proposes complex types of distribution of specimens, such as gradient-tussocky, areal-tussocky, areal-clumped, regular with clumps, areal with regular or three-element dispersion (Fig. 2).

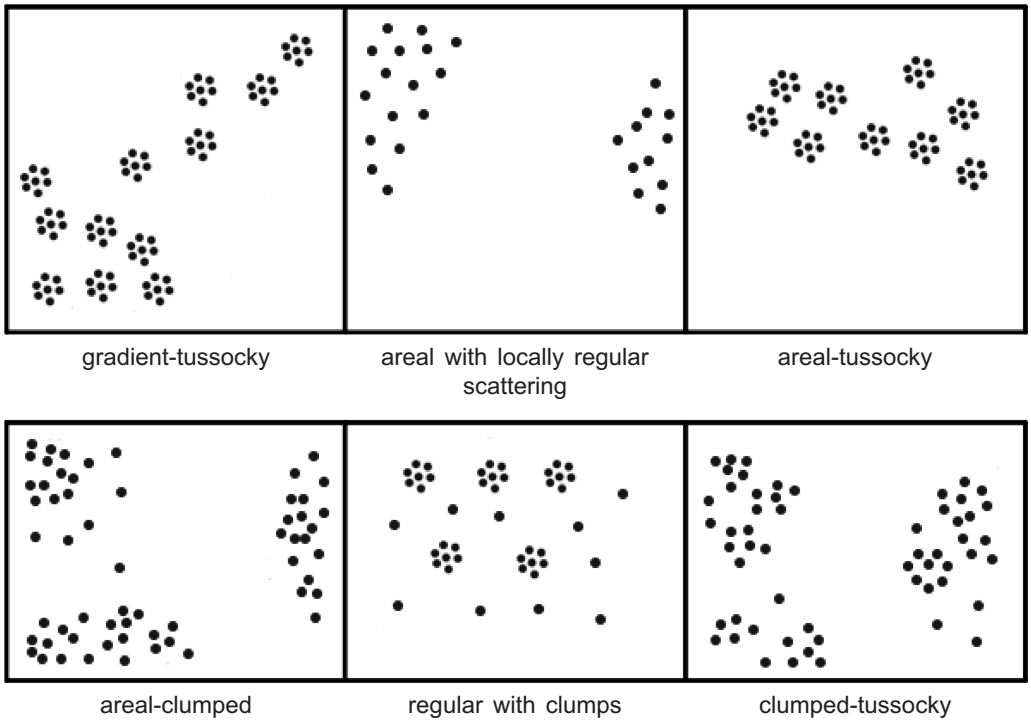


Fig. 2. Complex types of spatial distribution of plant populations (Falińska 1996 — altered)

Clumped distribution of specimens is usually encountered among the aforementioned types of spatial organization (Falińska 2002). According to Falińska (1996), among many abiotic factors enhancing the clustering of plants, irregular spatial distribution of nutritional and water resources, as well as heterogeneous light conditions, are the most important ones. The same author states that among phytocoenotic factors, the following should be emphasized: a space free of competition or a possibility that a spot is taken over by a specific species after withdrawal of competitors. Very rare, random spatial distribution of specimens results from the absence of a factor arranging the spatial structure of populations of a given species (Kershaw 1978). Random spatial distribution of specimens is

observed when there are unknown causes determining a given distribution. The extent and the range of interactions by abiotic, biotic and populational factors are subtle enough to be indiscernible for the methods applied for the evaluation of spatial variability.

Spatial dynamics of populations

Changes in the density and the spatial distribution of specimens in relation to life conditions and biological traits of a species can have diverse character. These changes could be significant and in time they can lead to important transformations in the spatial structure of populations, or also they can be revealed in the form of periodic and minor fluctuations (Falińska 2002). The causes determining the nature of structural transformations are usually connected with the developmental stages of populations, and thus with changes in the abundance, as well as with changes of environmental factors or also with the appearance of competitive species (Falińska 1996).

Three types of transformations are distinguished in the spatial structure (Wiąckowski 1998):

Successive — directional changes in the density of specimens are connected with the developmental stages of populations. Almost each population stage has a different type of spatial structure.

Fluctuating — in a certain period, density of specimens in a population is changing, only to return to the initial situation after some time. These changes are seasonal or long-term.

Pulsatory — minor changes in the density of specimens, which characterize almost every population, as well as their intensity, are usually small and not the same in different parts of a population's home range. These changes do not determine the transformation of the spatial structure or major deviations from a pattern in a given situation.

Habitat factors

Based on the previous researches on the spatial variability of a population, one can state that the distribution of specimens is determined by habitat factors and by interactions between specimens of their own and other species (Falińska 2002).

Attempts at explaining why a given species occurs in a given part of a home range usually begin with the analysis of habitat factors. Among them, special attention is paid to: water, light and soil properties, which are the factors determining the increase and the development of plants. The variety of habitat factors offers many possible interpretations.

Solar radiation

Solar radiation is both a factor necessary for life and an important limiting factor (Wiąckowski 1998).

Visible radiation, i.e. light, is necessary for the processes of photosynthesis and is a factor determining both daily and seasonal rhythms of plants (Wiąckowski 1998). It

is part of the electromagnetic spectrum, which on the Earth's surface comprises waves with the length corresponding to the visible spectrum (~ 390—760 nm), as well as part of the infrared waves with the wavelength above 750 nm and ultraviolet radiation with the wavelength less than 400 nm. The maximum coincides with ca. 500 nm (Kreeb 1979).

Solar radiation incident on seedlings is reflected, penetrates through leaves, and consequently, after absorption it, enables the process of photosynthesis. Photosynthetic active radiation within the wavelength range of 400—700 nm (PAR — Photosynthetic Active Radiation) is the most important radiation for this process (Hall, Rao 1999).

Light stress occurs in the case when photosynthetic pigments absorb too much PAR energy in relation to the possibility of converting this energy into chemical energy in the process of photosynthesis, or safe diffusion in the form of heat or emission in the form of chlorophyll luminescence (Murkowski 2004). Light stress can also occur at moderate PAR radiation, when other stress-related factors participate too, such as drought or contamination inhibiting the process of photosynthesis (Kopcewicz, Lewak 2002).

Too high light intensity can bring about some destructive effects on plants, called photoinhibition (Więckowski 1998). This can result in damage to an assimilation apparatus, oxidation of lipids and assimilation pigments.

Extremely high exposure results in the damage to proteins in chloroplasts, inhibition of electron transport and changes in chlorophyll fluorescence. Injuries to tissues containing chloroplasts are a frequent phenomenon, which is reflected in the development of colourless spots on the surface of leaves exposed to the sun (Kopcewicz, Lewak 2002).

The progressive decrease of the atmospheric ozone content, observed since the end of the 1970s, result in the increased UV radiation intensity, which has a destructive influence on plants. UV radiation is absorbed by a variety of compounds, which are of the primary significance for the functioning of cells, and this is the cause of serious injuries. These are mainly inhibition of protein synthesis, changes in the activity of hormones, changes in membranes, changes in the intensity of growth processes, respiration and photosynthesis. Cellular division is particularly sensitive to UV, which consequently results in the reduced growth of specimens.

In the conditions of post-industrial dumping grounds, the exposure to solar radiation significantly reduces the development of vegetation. Research indicates that slopes less exposed to solar radiation constitute more favourable habitats for the development of vegetation cover, as compared with a slope with steep inclination and southern exposure (Rostański 2006).

Temperature

The temperature influences all life processes of plant organisms (assimilation, respiration, transpiration, growth) by modifying the properties of membranes and the activity of enzymes; it changes the rate of chemical reactions, viscosity of cell sap, cytoplasm, juices of phloem and xylem (Wiąckowski 1998). The range of

thermal tolerance, determining the life processes of the majority of plants, fits within the broad limits from a few degrees to ca. 35°C, and is genetically conditioned.

The Earth's surface — by absorbing the solar radiation — warms up and thus becomes the source of radiation. Air masses adhering to the soil surface reflect the heat and warm up. With strong radiation, the temperature of plants rises above already high ambient temperature. Parts of plants located in the close proximity of soil are particularly endangered, especially at open sites where measurements have revealed the temperature of up to 80°C on the soil surface (Kreeb 1979). In such conditions, injuries to plants and particularly to seedlings are unavoidable.

Plants may starve at high temperatures, because respiration could be higher than photosynthesis; consumption of metabolites could be faster than their production (Wiąckowski 1998). In practice, high temperatures lead to their dehydration, and consequently to their withering.

Water

Water content in the soil and in the air is one of the main and multifaceted factors determining the development and life of plants. It has a fundamental influence on morphological characteristics and condition of particular specimens in a population. The influence of water does not only depend on the amount and the availability of water in the environment, but also on the intensity of other factors directly affecting the plants, for example the temperature and the light.

Water availability or water deficiency is the main factor determining the development of spontaneous vegetation on post-industrial dumping grounds.

The adverse effects of the lack of soil moisture intensify the deficit of water vapour in the air, as well as the excessive transpiration and evaporation caused by high temperature, particularly during summer (Białobok 1989). The amount of water in the soil has a direct influence on the production of plant biomass and biological characteristics of plants. When there is no water, stomata are closed, and at the same time assimilation is reduced. If water losses are high, irreversible structural changes may occur in the protoplasm due to dehydration associated with severe mechanical damage to its elements, as a consequence of major changes in the volume (Kreeb 1979).

Water shortage in the soil and in the air, particularly around single-growing trees, is the cause of accelerated occurrence and shorter duration of individual developmental phases. Such unfavourable life conditions for a specimen cause reduction of the evaporation surface area through withering and shedding of leaves. This leads to dwarfing of individual organs and reduction of their number, often contributing to withering of a whole plant.

Inhibition of the growth of leaf cells and at the same time reduction of its external surface is one of the earliest responses of a plant to moderate water stress. This kind of stress reduces the growth of shoots and branches, as well as leads to reduction of the total number of leaves on a plant. Long-lasting and increasing water stress in the environment can also cause accelerated ageing and shedding of leaves, resulting in the reduction of transpiration surface area. Water deficit in shoots affects

also the development of the root system. Inhibition of the growth of cells of leaves and shoots reduces carbon and energy consumption by these organs. Due to photosynthesis, still unlimited in these conditions, there is an increased supply and distribution of assimilates to young, growing roots that are located in the most watered soil zone (Kopcewicz, Lewak 2002). Therefore, the roots develop faster, which in turn facilitates a better water supply to a plant. As a result of this kind of adaptation, the shoot to root weight ratio changes in favour of the latter. The soil represents an irregular mosaic of spaces with different moisture contents; between these spaces the soil water moves, both in liquid or vapour state. The growth of roots towards the soil layer with higher water content can be regarded as the second line of defence against the drought (Kopcewicz, Lewak 2002).

Soil

Edaphic conditions are one of the main factors determining the life and the development of plants. The most favourable conditions for their development are created by their lumpy structure. It ensures easy penetration of roots and good aeration conditions, even with high water saturation of soil. The quality of soil depends on the ratio between the mineral and humus part, between the soil air and soil water. The soil of good quality should have the following volumetric ratio: mineral parts — at least 45%, 5% — soil humus, 25% — soil air and 25% — soil water (Wiąckowski 1998).

Soil in the post-industrial areas is usually destroyed through geomechanical, hydrological and physico-mechanical transformations. The following properties are changed: mechanical composition of soil and subsoil, their structure, physical properties, the humus content, abundance of mineral components, reaction, the moisture content, as well as specific microflora and microfauna. In extreme cases, the soil in the urban-industrial environment consists of the dead substrate, devoid of the accumulation layer and nutrients (Bolibok 1989). In such soils, plants cannot use capillary, condensation and subterranean water. The subterranean water level is usually strongly lowered. The increased soil reaction and the shortage of oxygen adversely affect microorganisms, and make the uptake of nutrients difficult for plants.

High concentrations of heavy metals (Cd, Cr, Fe, Ni, Pb, Zn) occur in the soil covering the ore-bearing rocks, in the soil near the dumps, or in dusts from metallurgical industry. Toxic effects of heavy metals are associated with their excessively high concentrations in a cell. This results in the reduced energy balance of cells, disturbances in mineral nutrition, reduction in the growth, accelerated ageing of tissues (Kopcewicz, Lewak 2002).

In open areas connected with industrial activities of man (post-industrial heaps), soil properties constitute the main habitat factor determining the rate of pioneer vegetation encroachment. Among other factors, reaction and toxicity of the substrate, the soil structure and the content of nutrients are important for the growth of plants (Rostański 2006).

Part Two

European white birch *Betula pendula* ROTH — general characterization of the species

The developmental biology of birch and adaptation capabilities of the species

The genus *Betula* includes ca. 35—60 species. Such a considerable number of species results from the fact that interspecific hybrids with a taxonomic rank difficult to determine are easily created. In Poland there are 7 species of birch, among which the European white birch is the most widespread and has the biggest economic importance (Gil, Kinelski 2003). This species grows in the whole country; in the mountains — up to the upper subalpine forest.

The distribution of *B. pendula* covers almost all Europe from the Mediterranean in the south nearly to latitude 70° in the north. The species is most abundant in northern Europe, where the distribution is more or less continuous in mixed forests and also fairly large pure stands can be found. In the western and southern parts of the range the distribution is more patchy and in the south silver birch is found mostly at the higher altitudes. The species is missing from Iceland, and most of the Iberian peninsula and Greece (Peinado, Moreno 1989; Atkinson 1992), (Fig. 3).

The family Betulaceae, taken in a broad sense, includes 6 genera: *Alnus*, *Betula*, *Carpinus*, *Corylus*, *Ostrya* and *Ostryopsis*. The family has been divided by several authors into subfamilies and/or tribes. In the latter case the Betulaceae only includes *Alnus* and *Betula*. In a recent survey of the family, Furlow (1990) recognized two natural subfamilies, the Betunoideae and the Coryloideae, the latter divided further into two tribes, the Carpineae with *Carpinus* and *Ostrya*, and the Coryleae with *Corylus* and *Ostryopsis*. As yet there is no consensus on the phylogenetic

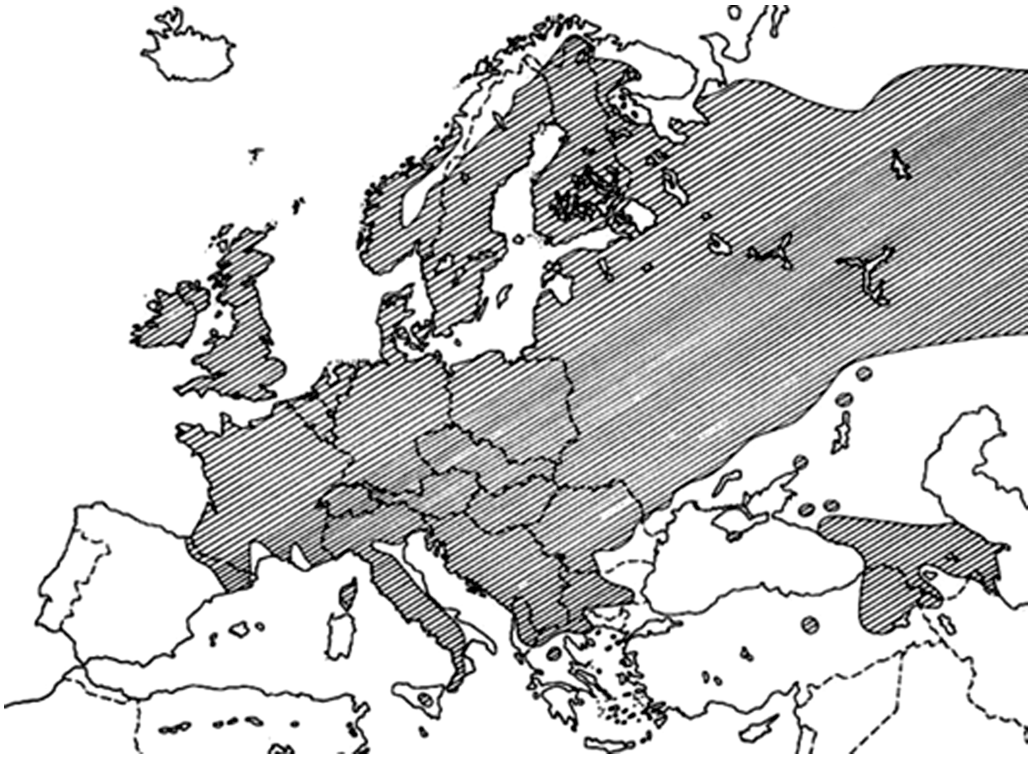


Fig. 3. Distribution range of *Betula pendula* Roth (after Suszka, Muller, Bonnet-Masimbert 2000 — altered)

arrangement of the genera. Most authors consider *Alnus* to be the least specialized genus.

Most standard books on dendrology give a division of the genus *Betula* into four sections: sections *Betula*, *Costatae*, *Acuminatae* and *Nanae*. Sections *Betula* and *Nanea* are very widely distributed in Eurasia and North America. Section *Acuminatae* is restricted to China and the Himalaya and section *Costatae* has a disjunct distribution in eastern Asia and the eastern (Atlantic) coast of North America.

In contrast to that of the family as a whole, the phylogeny of *Betula* has received less attention. Natho (1976) made a hypothetical diagram based on his studies of the hull and testa of the fruits. He found a number of relationships between subgenera of the sections, with the subgenera *Betulenta*, *Betulaster* and *Neurobetula* in a basal position. Both subgenus *Betula* and *Chamaebetula* are rather homogeneous groups and are seen here as derived from the same or different ancestors related to the modern subgenus *Neurobetula* (Seneta, Dolatowski 2009).

The European white birch is a short-lived tree reaching up to 25 m height (Suszka, Muller, Bonnet-Masimbert 2000), although in favourable conditions it can grow up to 30 m in height and 310 cm in perimeter at the trunk height of 130 cm (Hrynkiewicz-Sudnik, Sękowski, Wilczkiewicz 1990). The bark of young trees is

first brown and then white, due to a substance called betulin, which is present in the surface layers of phellem, whose crystals refract the light and cause a whitish colouring of the bark. The crown of trees is very well developed, loose, and in the case of old trees — with long and thin twigs hanging from boughs. Leaves are hairless with long petioles, double-serrate along margins; 3—8 cm long, triangular or rhomboid with acuminate tips. There are 2 opposite leaves on every dwarf shoot. Buds are hairless, sticky, enlarged at the base (Hrynkiewicz-Sudnik, Sękowski, Wilczkiewicz 1990). European birches are a species complex, where correct identification of *B. pendula* may be a challenge. Although quite similar, downy birch (*Betula pubescens*) has hairy leaves and shoots. Chemical and molecular markers are presently available for more definitive identification. These two species can also be distinguished cytologically: *B. pendula* has 28 chromosomes (a diploid species), whereas downy birch has 56 chromosomes (a tetraploid species). Despite this difference, the two species may occasionally hybridize (McAllister 1992).

Birch as a pioneer species

Almost all species of birch have extremely well developed pioneer traits. Owing to these properties, birch species are widespread, although there also rare and even endangered taxa. Nevertheless, the latter remark applies mainly to relict species or species associated with specific habitats (certain types of peat bogs). The present-day occurrence centre of species from the genus of *Betula* is located in the cold and moderately cold zone in the northern hemisphere, and thus in areas dominated by relatively young vegetation and strongly transformed by human activity during the last two millennia. Biological and ecological traits of birch species reveal excellent adaptations to habitat and environmental conditions developed under the influence of postglacial and Holocene processes. These traits enable the contribution, and sometimes the dominant role of birch specimens in the development, functioning and reconstruction of many communities (Bernadzki, Kowalski 1983; Houle 1990). Together with the entire flora and vegetation, birch specimens reveal seasonality of climatic characteristics and susceptibility of the whole environment to anthropogenic influence (Suszka 1979).

Plants with pioneer traits are defined as species, which have certain special biological and ecological properties due to which:

— they use extreme environmental conditions to perform their vital functions;
— they gain the ability of adapting to extreme conditions;
— have the ability of transforming the extreme conditions into conditions optimal for life of single organisms, populations and eventually whole biocoenoses;
— they outdistance other species in the process of conquest and colonization of new areas, they determine the course of initial phases of primary or secondary succession, but usually withdraw when an ecological system reaches the complete stability (Falińska 1990; Faliński, Pawlaczyk 1990; Falińska 1996; Dalling, Hubbell 2002; Debain, Curt, Lepart 2003; Flerchinger, Hardegree, 2004).

Birch is an important element in early stages of primary and secondary succession, which adapts not afforested or devastated lands to colonization by other

organisms. Birch, as one of the first pioneer species, occurs in new habitats owing to light, small seeds abundantly produced and transported by wind. Birch colonizes a new land relatively quickly, and wilding trees often form very dense and large patches. However, due to the fact that birch is highly photophilous, withering of trees is a very intensive process, so that the canopy of birch trees thins out relatively quickly. Traits of photophilous plant are revealed in the structure of a lamina, as well as in the transparent texture of a crown and mobility of leaves. With the maximum development of leaves, crowns of birch trees are permeable for even 37% of the full light, which enables the growth of many tree species under their canopy, and at the same time mitigates the extreme temperature fluctuations (Suszka 1979).

Birch also transforms the substrate and influences the development of good soil structure. Growing in poor habitats and reaching considerable sizes, birch specimens prove not only modest requirements of this species, but also transformation of the substrate favourable to the growth of trees. According to Bernadzki, Kowalski (1983), a characteristic feature of birch roots is active and rapid penetration of soil (up to one metre at the age of four years), therefore the author calls the birch a pioneer species in the transformation of compact soil layers. Birch, compared to pine, develops a stronger system of horizontal roots. With a little smaller number of roots of the first order, the number of roots of the fourth order is sixteen times higher as compared to pine. It appears from this that birch uses the surface soil layers more intensively compared with pine. These numerous small roots grow through the surface layers of the substrate, and growing thick they split the layers into small fragments. Also the process of withering of young trees, proceeding within a short time, leads to deposition of considerable amounts of organic matter in the soil. The action of birch roots may resemble a mechanism of soil structure formation. Together with birch, habitats are enriched by other forest plants and symbiont fungi, which increase the species diversity of a biocoenosis and participate in further transformation of a habitat.

Pioneering nature of birch is also expressed in early and abundant pollen production. Blooming of trees together with the development of leaves in early spring contributes to anemophily, and a large amount of pollen provides an opportunity for effective pollination of pistillate inflorescences. A relatively short reproduction cycle is yet another trait of pioneer species. Birch seeds mature late summer and seedlings appear before winter. Seeds are resistant to strong desiccation and low temperature, and can stay in the soil for the whole winter without losing its viability.

In the spring new specimens appear, supplementing the population of seedlings germinating in the autumn. The existence of a lasting accumulation of live seeds in the forest soil, potentially capable of germination is called a seed bank (Falińska 1996; Sarvas 1950). A long-lasting seed bank of the birch (Faliński, Pawlaczyk 1993) is not only an element of the species life strategy, but also a characteristic of a pioneer tree. Accumulation of seeds capable of germination in the soil facilitates the rapid occurrence of birch in places where stands of trees were destroyed — either as a result of logging or natural catastrophes. The existence of the soil seed bank in combination with a relatively high potential for reaching such places by

birch seeds coming from the surrounding habitats results in the fact that birch very quickly colonizes gaps developed as a result of such disturbances (Kullman 1986).

Adaptation of birch to unfavourable environment conditions

Maintenance of woodlots in urbanized areas, particularly in post-industrial areas, requires tolerant tree species resistant to unfavourable habitat conditions (Kubiak, Księżniak 2005). Birch becomes more and more important in the afforestation management. Suitability of *B. pendula* for tree planting in industrial districts results from considerable resistance of these trees to toxic emission around industrial plants. With respect to these characteristics, birch trees are characterized by high variability in their resistance to different chemical components of toxic emission, which can be best observed in the Upper Silesian Industrial Region. In extreme conditions, only specimens capable of environmental adaptation can survive. Therefore, within a birch population there is a great possibility of selecting specimens or populations that are most resistant to harmful emission of industrial plants.

Adjustment of plants to specific habitat conditions is defined as adaptation. Two types of adaptation are distinguished: phenotypic adaptation, which concerns acquired traits of a specimen and is not inherited, as well as genotypic adaptation — genetic changes occurring in a population and leading to evolutionary transformations (Stawicka, Szymczak-Piątek, Wieczorek 2000). The latter case of adaptation develops due to natural selection and mutation.

Adaptation to unfavourable habitat conditions is quite a common phenomenon in the world of plants. As emphasized by Falińska (1996), physiological, morphological and anatomic traits, as well as ecological requirements of plants result from interaction between two systems: genetic structure of organisms and a set of environmental factors. Modification of elements in one system disturbs the equilibrium and is reflected in unfavourable changes of organism's properties (Falińska 2002).

In general, plants respond with behaviouristic changes to smaller and short-duration fluctuations in environmental conditions. In the presence of bigger and long-lasting fluctuations of environmental factors, regulatory mechanisms are probably replaced by genetic mechanisms.

The European white birch is characterized by great capabilities of adaptation to specific habitat. This is possible due to broad ecological amplitude. Species of broad ecological amplitude form a mosaic of population, heterogeneous in respect of many ontogenetic traits. It is also worthwhile to emphasize that birch trees as anemophilous plants hybridize easily. One can obtain progeny from seeds with traits split to a different extent. Due to high genetic flexibility and under the influence of selection pressure (Stawicka, Szymczak-Piątek, Wieczorek 2000 i.e. total environmental pressure), they are able to develop traits that facilitate their survival.

Generative reproduction of birch

B. pendula is a monoicous and dioecious tree. Setting of generative organs takes place in the year preceding the flowering. Staminate inflorescences are being set at

the tips of long shoots at the end of spring and the beginning of summer. Already in July mitotic divisions stop in rachises (axes) of staminate inflorescences; they are still continued, however, in primordia of stamina. In late August microspores develop in anthers and in this form staminate inflorescences spend the winter (Atkinson 1992; Parala, Alm 1990). And thus, setting of staminate inflorescences takes place in long-day conditions, whereas their growth and pollen formation — in short-day conditions (Suszka 1979). Pistillate inflorescences enter a phase of winter dormancy in the form of primordia in axillary buds of dwarf shoots, and their growth and complete development takes place in spring together with the development of leaves (Atkinson 1992; Kullman 1984 b).

Staminate inflorescences consist of a rachis (an axis), on which individual flowers are located. Each flower consists of three bracts of a perianth borne in an axil, and a number of stamina whose anthers are divided up to their base (Parala, Alm 1990).

Pistillate inflorescences consist of many flowers clustered into groups of three, borne in an axil of ciliate bracts and reduced to pistils, each of them equipped with two stigmas. Those are double and bilocular pistils. Inside each of them there are two ovules, usually only one of them develops (Parala, Alm 1990).

B. pendula begins to flower when a tree reached the age of 5—10 years. Depending on the canopy of trees, however, and environmental conditions, trees may enter a phase of generative propagation much later, at the age of 20—30 year. First pistillate inflorescences appear 1—3 days before pollen production on the same individuals (Holm 1994a, b). The beginning of pollen production depends on the temperature — the higher the temperature the earlier the pollen production starts, whereas the amount of pollen and its abundance depends on weather conditions. Low temperature in spring has a strong influence on a drastic decrease of birch pollen production. High moisture content and reduced temperature considerably reduce the amount of free pollen in the air. In such conditions, parthenocarpic fruits develop. The period of maximum pollen production lasts for 2—3 days, and anthers release ca. 70—80% of pollen. During a day the most intensive pollen production coincides with afternoon hours, and the least pollen is produced during evening and night hours (Parala, Alm 1990). The release of pollen from anthers is not a mechanical phenomenon, instead it is subject to physiological rhythm. It turned out, in fact, that even a relatively high temperature of early night hours does not prevent sudden inhibition of pollen production (Suszka 1979; Parala, Alm 1990). Birch pollen is transported over the land by wind and turbulent air currents. The development of leaves reduces the wind velocity by 12—15% of the wind velocity over the canopy of trees. This facilitates falling of pollen coming from both the same stand of trees and pollen arriving from other areas. Pistillate flowers are capable of pollination during 2—3 days, and about three pollen grains settled on a single pistil (Atkinson 1992). During the years with average pollen production, the amount of pollen is sufficient for pollination of all pistillate flowers. Nevertheless, the percentage of empty seeds is often very high. The small weight of pollen grains, i.e. 6 ng, accounts for the poor ability of pollen tubes to penetrate

the ovules, which has a strong influence on the quality of seeds. Moreover, the efficiency of pollination and fertilization processes significantly affects the pollen viability, the ability of a pollen tube to puncture the cuticle of a stigma, as well as the physiological condition of pistils and ovules (Safford 1990).

Biology of setting of nuts

Birch fruits are small, flat, one-seeded nuts, wrapped from both sides by membranous wings with two stigmas on the top. Pericarp of seeds is built of three layers of cells impregnated with fatty substances. Permeability of involucres (cupule) is additionally reduced by the outer layer of cuticle. These properties enable birch nuts to float on the surface of water for about a month (Parala, Alm 1990). Depending on the weather conditions and geographic location, birch seeds mature in July and August. Initially green fructifications (catkins) gradually turn yellow and break down (Holm 1993). Injured fructifications break down early or stay as a whole till winter (Suszka 1979). They contain seeds of low sowing quality. Duration of setting and maturation of seeds depends on climatic conditions, however the temperature of the growing season seldom affects the viability of seeds (Suszka 1979; Parala, Alm 1990; Atkinson 1992).

A single tree produces $9 \cdot 10^6$ nuts (Atkinson 1992), and each fructification contains ca. 450 nuts. Monospermous (one-seeded) birch nuts are extremely light, the weight of 1 000 pieces comes to 0.17 g (Parala, Alm 1990; Atkinson 1992). The position of a fructification on a tree does not influence the quality of seeds, whereas the viability of seeds decreases towards the tip of a fructification. Fruiting of birch trees is characterized by apparent alternation. Every three years the average yield is higher, and thus the energy and capacity of germination are higher. During a good seed year, *B. pendula* produces ca. 2300 full seeds per one square metre of the soil surface and ca. 340 seeds per square metre during an average seed year (Parala, Alm 1990). Suszka (1979) observed that every 2—3 years the percentage of full seeds in the total seed material increases up to 60% during good years and below 35% in average years. The small weight of seeds and the presence of wings facilitates the spreading of birch nuts by wind over certain distances from a parental tree (Atkinson 1992). Sarvas (1950) stated that *B. pendula* nuts are spread in the quantity that enables effective regeneration over a distance of 40—50 metres.

Part Three

Description of the study areas

The zinc-lead dump

Geographical location and physiography of the research site

In geographical terms, the described research site is situated in the Silesia-Kraków Upland, which is a subprovince of the Małopolska Upland and belongs to the macroregion of the Silesian Upland (Kondracki 1988), (Fig. 4).

Birch specimens, from which the plant material was collected for the analyses, grow on the zinc-lead dump situated at the eastern part of the Metallurgical Plant "Silesia" in the city of Katowice and partly in the town of Siemianowice.

Dumping of wastes on the heap was continued over 140 years. The dumping ground is developed in the form of escarpments, hilltops and terraces. In the north-western part, there are numerous funnels and depressions. The terrain has large height differences with the extreme altitude datum of 288 m and 315 m asl. The relative difference in the altitude comes to 27 m. The total area of the dump was defined as 24.8 ha, and the deposited wastes are heterogeneous. Slag coming from muffle furnaces, as well as cinders from distillation and roasting furnaces are the dominant types of wastes. Cinders deposited on the heap for decades have mixed fine and coarse granulation. During dumping, part of the slug was agglomerated into sinters. Furthermore, remnants of chamotte bricks, pieces of muffles and construction debris were dumped on this dumping ground (Franiel 1996).

Hydrological conditions

The depth of the ground water level at the base of the dumping ground ranges from 1 to 1.5 m and do not reveal any deviations from the normal condition determined by the geological system (Franiel 1996).

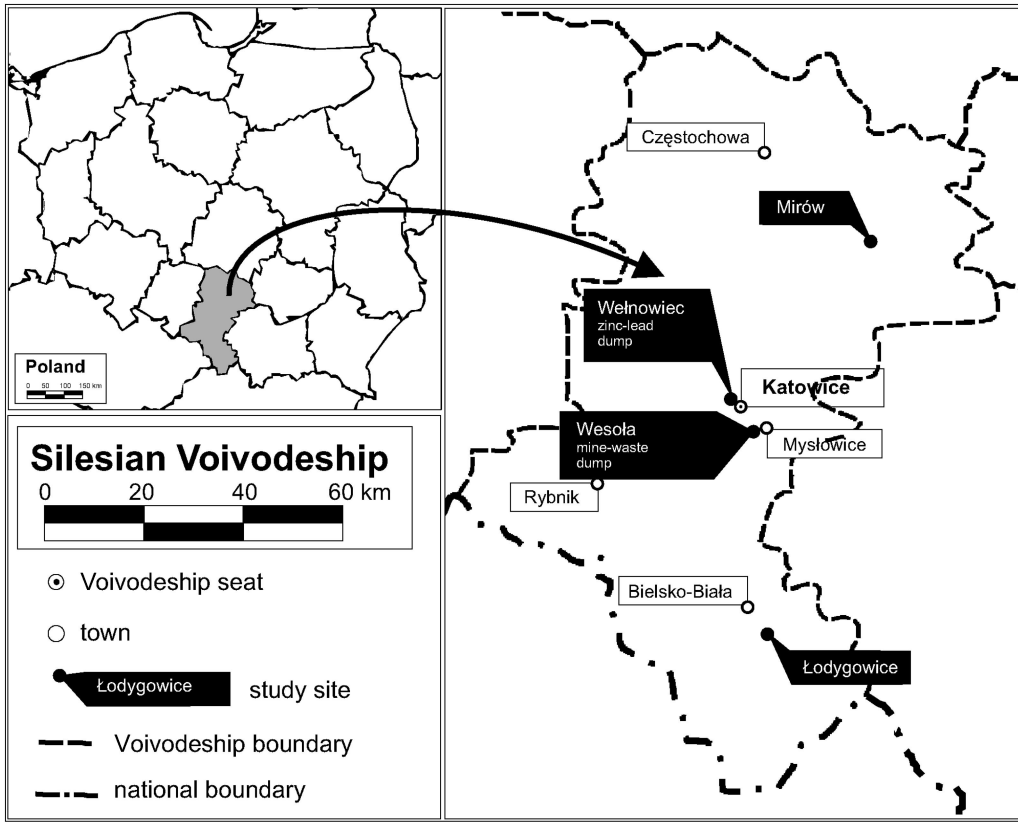


Fig. 4. Localization of research sites (after E. Małkowska)
Abbreviations: *D* — zinc-lead dump area, *C* — coal-mine waste dump area, *M* — Mirów, *L* — Łodygowice

Irrespective of the above hydrological conditions, one should additionally mention leakages of surface waters coming from precipitation and spring melting. Leakages of these waters into deeper layers depends on intensification and duration of precipitation.

In the nearest vicinity of the described area, the Rawa River flows in the southern part, and in the south-western part of the area — an emergency tailings pond is located.

Plants growing on the dump

As a result of the performed floristic researches, it was found that the number of species directly associated with the zinc-containing waste dump is small and does not exceed 10 species within a patch. *Festuca ovina*, *Silene vulgaris* and *Cardaminopsis arenosa* are the dominant species. In the oldest part of the dumping ground: *Betula pendula*, *Salix caprea*, *Populus tremula* and *Robinia pseudacacia* occur. The younger part of the dump is covered with vascular vegetation represented by: *Rumex acetosa*, *Agrostis stolonifera*, *Calamagrostis epigeios*, *Echium vulgare*, *Reseda lutea*, *Deschampsia caespitosa*, *Cardaminopsis halleri*, *Phragmites*

communis, *Plantago lanceolata*, *Tussilago farfara*, *Daucus carota*, *Eupatorium cannabium*. Also three moss species were identified: *Ceratodon purpureum*, *Bryum capillare*, *Bryum argenteum* (Tokarska-Guzik, Rostański, Klotz 1991).

The mine waste dump

Geographical location and physiography of the research site

According to Kondracki (1988), the described research site is situated in the Silesia-Kraków Upland, which is a subprovince of the Małopolska Upland and belongs to the macroregion of the Silesian Upland. The plant material was collected from birch trees selected on the mine waste (barren rock) dump KWK "Wesoła". The dump is situated in the town of Mysłowice, in the south-eastern part of the Katowice province. From the north, east and west the dumping ground borders on industrial areas, whereas from the south, through the land of the holiday centre "Wesoła Fala", it is adjacent to forest areas. Dumping of mine wastes in this place started already during the interwar period, but the last mine wastes from KWK "Wesoła" were still delivered in the 1970s. The area of the heap amounts to 4.43 ha and it developed in the form of a few ridges converging in the north-eastern part of the dumping ground. Depressions developed between ridges in the shape of channels, therefore the hilltops are divided and irregular. From the south-eastern part, escarpments of the dumping ground are vertical due to exploitation of wastes as a building material. The average altitude of the wasteland comes to 289 m. asl. The material building the dumping ground is barren rock, which is composed mainly of clay shales and sandstones. Wastes deposited on the dump were burnt; thermal processes still proceed only in younger parts of the dumping ground. The soil is in the early stage of development as its profile is not developed yet (Soska, Łoza 1974).

Hydrological conditions

From the south the dumping ground borders on the holiday centre "Wesoła Fala", which was created using the natural valley and the post-mining depression, and by damming up the waters of the Ławecki Stream. The reservoir stretches from the west to the east over the length of 700 m and the width of 100 m. The average depth of the reservoir comes to 1.7 m and decreases in the western part, and over the last 200 m it turns into a wetland overgrown with reed beds. There is a dyke in the southern part of the reservoir. Outside the dyke, there is a drainage ditch storing the precipitation water (Soska, Łoza 1974).

Plants growing on the dump

The area of the dump, apart from the thermally active areas and the most steep slopes, is covered with vegetation. Among trees coming mainly from self-seeding, the following species are present: *Betula pendula*, *Salix caprea*, *Populus tremula*,

Alnus incana. Among shrubs: *Sambucus nigra*, *Crataegus oxyacantha* and *Padus avium* are most frequently represented. In the southern and central part of the heap, the following species occur: *Plantago maior*, *Achillea millefolium*, *Tussilago farfara*, *Stellaria media*, *Calamagrostis epigejos*, *Deschampsia caespitosa*, *Deschampsia flexuosa*, *Poa annnua* (Soska, Łoza 1974).

The research site in Mirów

Geographical location and physiography of the research site

According to Kondracki (1988), the research site situated in Mirów (the commune of Niegowa) is included in the macroregion of the Kraków-Częstochowa Upland, the subprovince of the Silesia-Kraków Upland and the province of the Małopolska Upland. In geological terms, it is located within the Silesia-Kraków Monocline. From the west it borders on the Upper Silesian depression, from the south on the Sub-Carpathian depression, whereas from the east on the Miechów Basin. Three main structural stages are distinguished in its structure: old-Paleozoic rocks, Mesozoic formations and the youngest — Cainozoic formations. In the Mesozoic plate, upper Jurassic formations dominate with the thickness of more than 100 m, composed of marls and rocky limestone. Cainozoic formations are deposited evenly on older formations, smoothing and covering tectonic and morphological irregularities. These are mainly sands deposited on rubbles and limestone eluvia.

The development of soils in the studied area is mostly affected by lean Pleistocene sands and limestone debris. Both these rocks determine a different soil-forming process. Depending on the percentage contribution of limestone debris, the soil reaction can oscillate between strongly acid and basic.

Hydrological conditions

The studied area belongs to two main drainage basins of the Oder and Vistula Rivers. The drainage basin of the Oder, which comprises the northern and south-western part of the studied area, includes mainly the Warta river basin. Tributaries of the Vistula River drain the central-eastern and southern part of the area. The water deficit characteristic of the studied area is determined not only by geological structure, but also by altitude in relation to adjacent areas. The studied area located around the watersheds is drained in all directions, both through surface and underground runoff. Therefore, it does not receive surface or underground waters from outside, instead it supplies the lower-lying areas with the water (Wika 1986).

Plants of the studied area

The forest habitat within which a research site was selected, can be described as a degeneration stage of pine forest. Podzolic soils, moderately and strongly

podzolized, dominate at this site. They developed on Pleistocene sands with large thickness. In the tree layer, *Pinus sylvestris* and *Betula pendula* occur most frequently. The shrub layer is represented by *Populus tremula*, *Salix caprea*, *Quercus robur*, *Frangula alnus*, *Sorbus aucuparia*. Whereas in the herb layer the following characteristic species are present: *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Calluna vulgaris*, *Festuca ovina*, *Poa pratensis*, *Deschampsia flexuosa*, *Plantago lanceolata*, *Hieracium pilosella*. Mosses are represented by *Pleurozium schreberi* and *Brachythecium curtum* (Wika 1983).

The research site in Łodygowice

Geographical location and physiography of the research site

In geographical terms, the commune of Łodygowice, in the territory of which the research site was delimited, is included in the province of the Carpathians and the Subcarpathians, the subprovince of the External Western Carpathians and the macroregion of the Western Beskids (Kondracki 1988). The commune of Łodygowice is situated in the central part of the Bielsko-Biała Province and it borders with the village of Czernichów from the east, with the town of Żywiec from the north-east, with the commune of Szczyrk from the west, with the commune of Wilkowice from the north and with the commune of Lipowa from the south. The northern and eastern part of of the commune area is situated on the edge of two mountain ranges: Beskid Mały and Beskid Żywiecki, in the central part of the Żywiec Valley (Sobol 1982). Within the Żywiec Valley, the absolute height ranges from 400—500 m asl. Beskid Mały is characterized by steep slopes with considerable inclination (above 30%) and high relative altitude 400—500 m asl. The area of the commune is situated within the Silesian Nappe, near the Magura thrust front. In the area described, there are Cretaceous and Tertiary formations. Godula and Istebna beds come from the Cretaceous period, forming shale — sandstone complexes with limestone inclusions in the southern part of the commune. Beds of submenilite and menilite Eocene, represented by fine sandstone flysch, come from the Tertiary period and are located in the central and southern part of the commune. Strata of flysch shales and sandstones are covered with Quaternary sediments. They are represented by clays, silty clays and compact silty clays, as well as argil, gravel and pebbles covered with a layer of alluvial soils (fluvisols) in river valleys (Sobol 1982).

Two main types of soils occur in the commune area: fluvisols and acid brown soils. Gley and peat soils cover a small area. Brown soils dominate in the commune of Łodygowice and are deposited in lower parts of slopes, as well as at the bottom of valleys. These are medium skeletal, sandy clay loam, with a well-developed level of humus and a rich sorption complex. Whereas fluvisols occur in valleys of larger rivers, and usually have mechanical composition of more or less stony loamy sands (Sobol 1982).

Hydrographic conditions

The studied area is drained by the upper reaches of the Vistula River and its tributaries. Owing to a large amount of precipitation, considerable inclination of slopes, poor permeability of the flysch substrate, the studied area is characterized by a dense waterway network. The Żylica River and its tributaries are characterized by a considerable variation in water levels, up to a few metres, and large unit runoff. River valleys are morphologically heterogeneous. Apart from V-shaped, at present deepened valleys, in the mountain range of Beskid Żywiecki there are also box forms over which gravel bank is being moved. Slopes of valleys are affected by surface ablation and rill wash along furrows (Dobija 1983; Starkel 1991).

Plants of the studied area

Forests cover ca. 26% of the whole commune area. Two following plant communities were recorded here: mountain grey alder floodplain forest, occurring along almost all larger brooks, and lower subalpine fir — spruce forest. The tree layer of the latter one is composed of *Picea abies*, *Fagus sylvatica* with some admixture of *Abies alba*, *Acer pseudoplatanus*, *Sorbus aucuparia* and *Betula pendula*. Spruce regenerates quickly under the birch canopy. The herb layer is mainly composed of the following species: *Vaccinium myrtillus* and *Dryopteris dilatata*, as well as accompanying species: *Oxalis acetosella*, *Deschampsia flexuosa* and *Athyrium filix-femina*. The layer of bryophytes is represented by *Polytrichum formosum* and *Plagiothecium curvifolium*. Limited forestry favouring spruce planting, leading to permanent habitat changes, contributed to considerable spreading of the lower subalpine fir — spruce forest in the mountain range of Beskidy (Wilczek 1995).

Climatic conditions of the studied areas

According to the division into agricultural-climatic regions, the research sites in Katowice, Mysłowice and Mirów are included in the Częstochowa-Kielce district (Romer 1949).

The slag heap in Katowice and the mine waste dump in Mysłowice are included in the macroregion of Silesian Upland (Wyżyna Śląska), which is characterized by high heterogeneity and irregularity of climate. Warm air masses flow from the south through the Moravian Gate (Brama Morawska) and interact with arctic and continental air inflowing from the north and west. The amount of precipitation ranges from 310 mm to 860 mm. The average January temperature amounts to –1.5°C, July 17.6°C, and the annual average temperature — 8.2°C. South-westerly winds prevail, with the average velocity of 25 m/s (Kozłowska-Szczęsna 1983).

The research site located in the village of Mirów, in the territory of the Kraków-Wieluń Upland is characterized by slightly cooler climate, with more

precipitation compared to the Silesian Upland. The average January temperature ranges from –2.5°C to 18°C in July. The average annual temperature is ca. 7°C. In general, the precipitation in this area is relatively high and ranges from 600 mm to 850 mm. The duration of the growing season ranges from 200 to 210 days. West and south winds predominate in the distribution of winds. Owing to rich land relief in the studied area, local diversity of climate is high. This has a strong influence on the distribution and the development of plant communities (Kondracki 1988; Starkel 1991).

According to Romer (1949), the commune of Łodygowice is located within the zone of mountain climate. It is characterized by variability of climatic elements, which are heterogeneous and conditioned mainly by altitude. Large local climatic differences are caused by easy overheating of valleys and southern slopes during the day and inflow of cool air into the valleys at night. In the commune area, one can distinguish two climatic regions (Hess1965):

1) moderately cool region from 680 m. asl with average annual temperature of 4—6°C.
2) moderately warm region from 680 m. asl with average annual temperature of 6—8°C.

According to Kondracki (1988), the village of Łodygowice is included in the Sub-Carpathian region. Duration of the growing season ranges from 210—220 days, and the number of days with slight frost ranges from 100 to 150. During the year the majority of precipitation occurs between May and August with the maximum in July. During that month, areas located at the highest altitude receive ca. 200 mm precipitation, whereas the minimum precipitation of ca. 80 mm falls between January and March.

Part Four

Material and study methods

The research material and period

The research focused on: leaves, inflorescences (aments), fructifications, nuts and silver birch's seedlings. At four research sites, ten trees were selected in the age class from 20 to 50 years. At each tree, a twig was selected with a diameter of 1.4—2.1 cm with generative long and dwarf shoots. In order to perform researches on the spatial variability of *B. pendula* seedlings, and evaluate their biometric parameters, research plots were established in the zinc-lead dump and in Mirów.

The research was conducted between 2005—2008 and 2009—2010. In the first research year, methods for collection and analyses of plant material were compiled. The experiment was divided into two — field and laboratory — parts. In the field part, the number of birch leaves, their surface area and the content of photosynthetic pigments were determined at the time of full development of leaves. Biometric characteristics of birch inflorescences and fructifications were identified at the beginning and at the end of the growing season. In the laboratory part, the viability of pollen and the seeding value of seeds were analysed. Pollen germination was carried out on the nutrient agar, whereas germination of seeds on the filter paper in Petri dishes. These experiments were carried out immediately after collection of plant material in April and September every year. In order to perform researches on the spatial variability of *B. pendula* seedlings, as well as to evaluate their biometric parameters, 6 research plots were selected with the dimensions of 10 m × 10 m each. Four research plots were located in the zinc-lead dump and two of them were located in Mirów. Field studies at the plots: H-I, H-II, M-III were carried out in June in 2009, and at the sites: H-IV, H-V, M-VI in June 2010.

Field studies

The number of leaves and the lamina surface area on selected birch twigs

At each research site, during the full development of leaves (at the end of June), all leaves were counted on selected birch twigs. In order to determine the lamina surface area, 30 leaves were collected from dwarf shoots located in the central part of a twig. Immediately after sampling, leaf area was measured with a leaf-area meter (Delta T-Devices Ltd., England). Leaves were preserved for further analyses by placing them in a lightproof container. The researches were carried out for three consecutive growing seasons 2006—2008.

The content of photosynthetic pigments in birch leaves

The content of pigments was measured with the method proposed by Hendry, Grime (1993) and Linder (1974). The birch leaves brought from the research site in a lightproof container were being cut in the dim light into small fragments, rejecting necrotic parts and parts containing more mechanical tissue (e.g. parts of leaves with a midrib), and then carefully stirred. From the so-prepared material, four 0.20 g samples were collected: two for extraction of pigments, and two for determination of dry mass; the material was dried to constant weight in 105°C. Samples prepared for extraction of pigments were ground in a small amount of 100% acetone in a porcelain mortar with some addition of quartz sand and a small amount of magnesium carbonate as a buffering substance. During extraction, a mortar was kept in ice. The extract was decanted into a vessel, also placed in ice, and the process was carried out in the dim light until 50 ml of the extract was obtained. Thus the extract obtained was centrifuged for 10 minutes with 3 500 rpm. The refined extract was poured into flasks and readings were taken on a spectrophotometer Cecil CE 2011 (England), measuring the absorbance of the solution. The content of pigments was calculated from the formulas presented by Lichtenthaler, Wellburn (1983):

$$C\text{cla} = 12.7 \times A\ 663 - 2.69 \times A\ 645$$

$$C\text{clb} = 22.9 \times A\ 645 - 4.68 \times A\ 663$$

$$C\ \text{carot.} = (A\ 480 + 0.114 \times A\ 663 - 0.638 \times A\ 645) \times V \times 10^3 \times 112.5^{-1}$$

$A\ (x)$ — absorbance value for waves with the length of (x) nm,
C — mg of a pigment per 1l solution,
V — extract volume.

The average concentration was expressed in mg of pigment per 1 g dry leaf mass ($\text{mg} \times \text{kg}^{-1}$ DW).

Determination of biometric characteristics of inflorescences and fructifications

For three subsequent growing seasons of 2006—2008 during birch pollen production, pistillate and staminate inflorescences were counted on each selected birch twig. The length of staminate inflorescences was determined before they released their pollen at the end of winter, whereas the length of pistillate

inflorescences was measured on the last day of intensive birch pollen production. The length of staminate and pistillate inflorescences were measured with an electronic calliper.

In August, in each growing season of 2006—2008, ten fructifications were collected from every selected twig. The length of each fructification and the total number of nuts were determined in a laboratory, splitting the nuts into empty and full ones with the use of a binocular.

Laboratory tests

Pollen germination on the nutrient agar

During intensive pollen production of birch trees, staminate inflorescences were collected in the field in order to examine the pollen viability. The research was carried out for three consecutive growing seasons of 2006—2008. Immediately after the inflorescences were brought to a laboratory, the pollen was brushed off from anthers onto microscope slides with nutrient agar. The nutrient agar was prepared from a mixture of sucrose and agar "Difco", as well as distilled water in a ratio of 1 : 2.5. A slide together with nutrient agar and pollen was placed in a glass chamber in which the humidity over 90% and the temperature of 21°C was maintained. After 1, 2, 3, 24 hours, the growth of a pollen tube was observed. Germinated pollen grains were counted in 10 replications, 50 grains each, in the visual field under a light microscope (Zaufal 1993; Pietarinen, Pasonen 2004).

Germination of seeds

Sowing of seeds was performed immediately after collection of fruits. For every research plot, 20 Petri dishes with filter paper were prepared, onto which 25 birch seeds were being sown and placed in a thermostat with a temperature of 23°C. Germinating seeds were watered with distilled water. Germinated seeds were counted every day. A single series lasted for two weeks.

Based on the data obtained, the germination power of seeds and the Pieper coefficient were calculated, the latter as a determination of the germination rate and energy according to the number of days with germination of seeds of a given sample (Lityński 1977; Grzesiuk, Kulka 1981; Hendry, Grime 1993):

$$W = \Sigma(d \times pd) \times k^{-1}$$

d — a subsequent day of germination,
pd — the number of seeds germinated on a given day,
k — the total of all germinated seeds.

Geostatistical method

The ecologists' interest in the issues related to spatial variability of populations and plant communities is followed by a rapid development of methods which ensure the description and analysis of spatial structure of the studied phenomena. Among them, the geostatistical method becomes more and more popular.

Methodological aspects

Statistical methods, commonly applied to describe the variability, at the beginning assume that observations are independent from each other, which constitutes an obstacle to their thorough description and analysis. Most of the processes occurring in the nature are in fact burdened with spatial autocorrelation, which means that we are dealing with observations that are naturally closely interdependent — correlated with each other (Usowicz 1999). It turned out, however, that the phenomenon of autocorrelation needs not to be an obstacle to the knowledge and understanding of the spatial variability. Ecologists realized that it constitutes a significant element of the spatial structure, which can have important ecological consequences, and the knowledge about which can have great significance for the explanation of phenomena occurring in ecosystems (Kapusta 2004).

In such a case, a new method describing the variability — geostatistics is of particular importance. The geostatistical method, which takes the spatial correlations of the studied variables into account, constitutes a natural supplement to traditional statistical methods so far applied in ecology (Dębowska, Zawadzki 2005).

Innovation of the presented method consists in the fact that it permits description of the spatial structure with many details taken into account (autocorrelation, *sill*, *nugget*, *range*).

Spatial autocorrelation

Autocorrelation, which accompanies almost all natural processes, is manifested in the fact that observations close to each other are going to be more similar than those distant from each other (Giętkowski 2007). In accordance with the above statement, if a value of a certain variable was measured at a given point, for example the moisture content, one can expect that such a measurement repeated at a neighbouring point will not be much different from the previous one, but a measurement taken at a certain distance will be completely different (Kapusta 2004). In other words, values of the moisture content measured sufficiently close to each other are going to be correlated with each other, and a degree of correlation (spatial autocorrelation) will depend on the distance between the measuring points. Geostatistical analysis is intended for analysis of spatial relationships of data, i.e. their mutual correlation and the presence of spatial structures in their distribution (Cohen, Spies, Bradshaw 1990).

Elements of geostatistics

A variogram is the main tool of geostatistical analysis — a function describing the average heterogeneity of data (semivariance) according to the distance between each other (Kopczewska 2006).

A value of semivariance $2\gamma(h)$ is determined by the formula:

$$2\gamma(h) = 1/n(h)\Sigma[Z(x_i) - Z(x_i + h)]^2,$$

where:

$Z(x)$, $Z(x + h)$ — values of the studied variable at the points situated at a distance of h from each other;

$n(h)$ — the number of pairs of measurement points distant by h.

Mathematical functions — spherical, exponential, Gaussian — are fitted to an empirically defined variogram (Usowicz 1999).

An example of an empirical variogram together with a fitted spherical model is presented in Fig. 5.

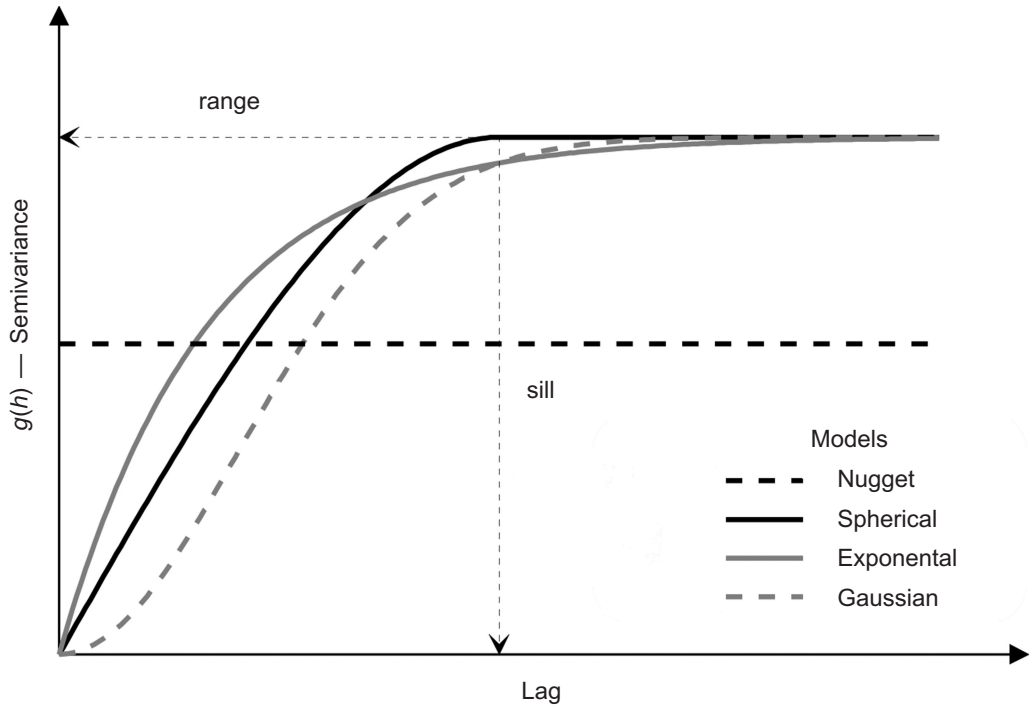


Fig. 5. A theoretical variogram (after Kapusta 2004 — altered)

The analysis of different forms of theoretical variograms permits the description of spatial variability in quantitative categories by means of defined parameters.

Three characteristic parameters are distinguished for a semivariogram: *sill* (threshold), *range*, *nugget* (the nugget effect).

The initial value of the function is the lowest one, because values of a variable (moisture content, density of specimens) at adjacent points are usually very similar to each other. For several subsequent distances *h*, semivariance values gradually increase until a variogram reaches its maximum level of variability defined as *sill*. The distance *h* at which this maximum occurs, is defined as a *range* and it is one of the main parameters of a variogram. The *range* informs us about the range of autocorrelation. Its high values (in this case 300; Fig. 3) prove great spatial cohesion of a variable, which is reflected in the maintained similarities between the points, even quite distant from each other (Kapusta 2004). Usually spatial variability of ecological phenomena is not perfectly continuous, which means that adjacent points can differ considerably from each other in a measurement value. In the structure of a variogram, this phenomenon is observed as the *nugget* effect. The higher the contribution of *nugget* in the structure (total variance), the smaller the significance of autocorrelation for the spatial variability development.

Modern programs automatically select an appropriate model and fit it to empirical data, which makes the assessment of spatial structure parameters entirely objective.

The significance of autocorrelation in ecological studies

The phenomenon of autocorrelation accompanies almost all natural processes. Autocorrelation, in other words a spatial relationship of variable's values, results from the spatial continuity of the environment. Physical space is continuous in the sense that single points are never completely isolated from the surroundings and can mutually influence each other. In this kind of space, the value of a variable describing a given process occurring in one place will affect values in the near or further vicinity (Kapusta 2004). Bearing this in mind, one can assume that spatial distribution of values of the studied variable is not random, but is characterized by ordered structure.

Georgie Matheron from the Centre of Geostatistics in Fontainebleau, France was the first scientist who described and formalized the aforementioned relationship in 1962—1963, as well as presented the theoretical basis of a new mathematical method for describing the variability — geostatistics (Mariol 2000). In his dissertation, Metheron assumed that each process occurring in the nature is characterized by a certain degree of continuity, which is statistically measurable. There are no phenomena that would be characterized by a completely random pattern of spatial distribution; however, a sampling scale often turns out to be too large to observe the continuity.

In the broadly defined ecology, there are more and more papers where authors prove that the variability studied within a small fragment of space is seldom random, often considerably high and has a mosaic structure with different degrees of autocorrelation. Heterogeneity is common even in the habitats, which at first glance seem to be relatively homogeneous. It is best presented in the paper by Nakamura (1979, after Kapusta 2004), in which the most striking is the fact that the environment seemingly very homogeneous as the soil of an urban lawn actually

is not so homogeneous, and the spatial structure of the studied potworms is not even or random. A small range of autocorrelation implies that within 1 m^2 of a plot, the count of potworms changes relatively rapidly. Areas with high density of specimens occur alternately with areas where potworms are rare, which means that spatial pattern is mosaic. Perhaps, the variability of physicochemical soil parameters at the scale of 1 m^2 is a sufficient reason for formation of clumps.

Assumptions of geostatistical analysis

Geostatistical tools should be applied to data with normal distribution. If applied to variables with the skewed distribution, the true spatial structure becomes distorted (Kapusta 2004). In order to obtain reliable information about the structure of autocorrelation, the studied phenomenon must be stationary (Usowicz, Usowicz 2004). The stationarity means that the average value of a variable does not depend on the location of a measuring point, in other words it is free of the large-scale influence by the spatial trend. Trends often result from the external influence in relation to the studied phenomenon (for example inflow of ions, which could form a pH gradient in the studied area). In such a situation, the average value of the measured variables can be higher in certain regions as compared to others (Kapusta 2004). Superimposition of a trend on a local variability pattern makes the identification of the spatial structure difficult, because a trend changes the shape of a variogram (Gumiaux, Gapais, Brun, 2003). A change in the shape of a variogram is reflected in its constant increase preventing the determination of the value *sill*. In order to meet the assumption about the stationarity of a phenomenon, a trend from a data set should be removed, and the analysis should be performed on the remaining part of the data. On the other hand, variograms calculated on raw data may become a useful exploratory tool used to search for spatial tendencies.

The spatial variability of *B. pendula* seedlings

In order to perform research on the spatial variability of *B. pendula* seedlings, as well as to evaluate their biometric parameters, 6 research plots were selected with the dimensions of 10 m × 10 m each. To facilitate the observations, they were divided into smaller 1 m plots (Figure 6). Four research plots were located within the area of the zinc and lead-containing waste dump of the Metallurgical Plants "Silesia" (H-I, H-II, H-IV, H-V). Two of them were located in the area relatively free of industrial contamination — in the village of Mirów (M-III, M-VI).

Measurements of the following variables were taken on the above-mentioned sites:

— Density of seedlings (specimens up to 10 cm) *B. pendula*;
— Biometric characteristics of larger specimens (above 10 cm);
— Habitat parameters: soil moisture and intensity of solar radiation (PPFD).

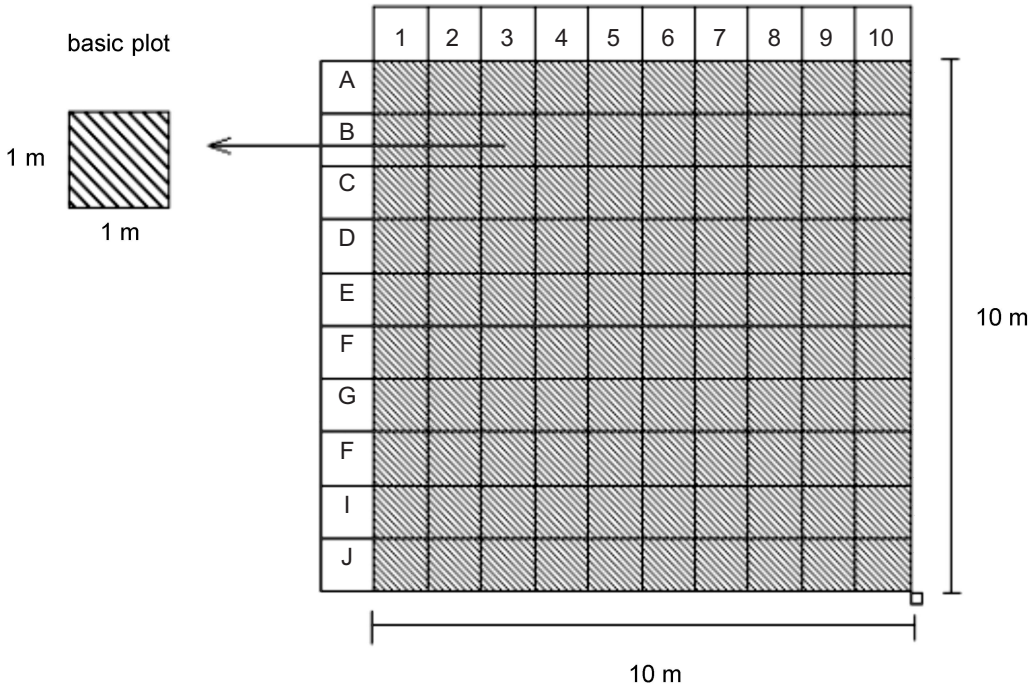


Fig. 6. Diagram of the research plot

The research sites were located in different areas of the heap created as a result of the activity of Metallurgical Plants "Silesia". Two measurement sites: H-I and H-II are located in areas of the latest dumping (ca. 30 years after dumping was finished) and where slow encroachment of pioneer vegetation was observed, the two other sites — H-IV and H-V — in older areas (over 60 years after dumping was finished, overgrown with dense vegetation consisting mostly of dense turf *Calamagrostis epigejos* (L.) Roth).

The aforementioned measurement positions were located at the foot of the slopes on the western side of the heap.

Research sites M-III and M-VI designated in the Mirów were located in the transitional zone between mixed forest and the meadow that was not exploited agriculturally for decades. Site M-III was located next to the forest, whereas site M-VI at a certain distance from the forest (200 m).

Field studies at the plots: H-I, H-II, M-III were carried out in June in 2009, and at the sites: H-IV, H-V, M-VI in June 2010. The soil moisture content was measured twice. The second measurement was repeated in September.

Research plots with the dimensions of 10 m × 10 m were divided into 100 identical squares — basic plots with the size of 1 m^2 within which the material was collected. The count of seedlings and the density (the number of individuals per 1 m^2) were determined by counting the specimens of *B. pendula* in successive squares — basic plots. The soil moisture content was measured with moisture meter HH 2 (Delta T-Devices Ltd., England).

In order to measure the photosynthetic photon flux density (PPFD), electronic phytophotometers OPTEL FR-20 were used, calibrated in μmol $m^2 \times s^{-1}$. Measurements were taken with clouded sky at a research site and in the open area simultaneously, which enables us to calculate the relative photosynthetic photon flux density (the ratio of photosynthetic photon flux density PPFD within a selected research site Q_z and the full light flux density O_o) according to the formula:

$$\text{PPDF} = Q_z / O_o \times 100\%.$$

Using measuring tools (electronic calliper), biometric parameters of larger specimens (above 10 cm) were determined. Observations and biometric measurements were applied to the following plant traits:

— The height of a plant — the distance from the ground level up to the tip of the longest shoot;
— The number of branches;
— The number of leaves on the leader shoot.

For studies on the spatial variability, all specimens were being counted, whereas for studies on biometric characteristics — only plants above 10 cm high.

Statistical methods

The results of measurements describing the photosynthetic apparatus of birch and biometric characteristics of generative organs were statistically analysed. Tukey's multiple range test was applied for indicating the significance of differences between research sites in relation to a selected parameter. Also the correlation analysis was applied in order to define significant relationships between analysed parameters. In order to compare the average values of biometric characteristics of seedlings between the research sites, univariate analysis of variance was performed with the significance level of $p = 0.05$. If the influence of any of the independent (grouping) variables was significant, then the analysis of variance was completed with the post-hoc Tukey test, which verifies the significance of differences between particular research sites. In one case, i.e. for the number of branches, the collected data were analysed with the chi-square test (χ^2). Statistical calculations were performed with the software STATISTICA 7.1 (StatSoft, Poland).

Data regarding the count of seedlings, the soil moisture content and PPFD were analysed in respect of their spatial variability by means of the geostatistical method. The remaining material, i.e. biometric parameters were analysed by means of statistical tests.

In order to examine the development of spatial variability of silver birch seedlings, as well as to determine which factors affect their spatial patterns, the new method (apart from classical statistics) describing the variability — geostatistics was applied in the presented work.

Spatial analysis of the studied variables (density of *B. pendula* seedlings, soil moisture and solar radiation intensity) comprises the following stages:

— Preliminary analysis of the collected data and evaluation of the basic statistics;
— Visualization of variables;
— Determination of empirical variograms for the studied variables and selection of theoretical variograms;
— Determination of variograms' envelops.

In this study, a variogram is the main tool of geostatistical analysis. A particular emphasis was put on the description and the use of information contained in variograms.

Based on the direct measurement data, empirical variograms were determined for particular variables. Next, mathematical models were fitted to these variograms. The goodness of fit of the models of theoretical variograms to the empirical data was determined with the coefficient RMSE (root of mean-square error) and AIC (the information criterion of Kaik). Values of *range*, *nugget* and *sill* were determined. Envelops for variograms were created — a type of a confidence interval. Envelops determine a confidence interval for a variogram if spatial autocorrelation is missing.

All calculations related to geostatistical analysis were performed with the software R-CRAN (*Comprehensive R Archive Network*, Kopczewska 2006). Additionally, in order to draw variograms, the program VESPER (http: Sydney.edu.au/agriculture/acpa/software/vesper /shtml) was used.

Part Five

Results

The photosynthetic apparatus of birch

The following parameters describing the photosynthetic apparatus of birch were studied: the content of *chlorophyll a*, *chlorophyll b* and carotenoids, the ratio of *chlorophyll a* to *b*, the number of leaves and their the surface area.

The content of *chlorophyll a* in birch leaves

In 2006, the lowest concentration of *chlorophyll a* — 0.52 $mg \times kg^{-1}$ DW was recorded in leaves of birch specimens from the zinc-lead dump, whereas the highest concentration — 0.77 $mg \times kg^{-1}$ DW in leaves coming from the area of Mirów (Table 1A). The T test revealed significant differences only for the research site located on the zinc-lead dump (Fig. 7).

In 2007, the lowest content of *chlorophyll a* — 0.35 $mg \times kg^{-1}$ DW was recorded in leaves coming from Mirów, and the highest one — 1.77 $mg \times kg^{-1}$ DW in leaves from the zinc-lead dump (Table 1B). The T test revealed the statistical significance of differences for the research sites located on the slag heap and in Mirów. For other research sites, the differences were statistically insignificant (Fig. 8).

In the subsequent research season of 2008, the content of *chlorophyll a* in birch leaves ranges from 0.34 $mg \times kg^{-1}$ DW for the research sites of both dumps to 0.36 $mg \times kg^{-1}$ DW in leaves of birch specimens from Łodygowice (Table 1C). The T test revealed that there are no significant differences between the three research sites (Fig. 9).

Table 1. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula chlorophyll a* concentration for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 4.21$; $p < 0.01$			
	D	C	M	L
D		0.030*	0.022*	0.045*
C	0.030*		0.999	0.998
M	0.022*	0.999		0.990
L	0.045*	0.998	0.990	

B

Site	ANOVA/MANOVA $F_{3,36} = 126.82$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.004*	0.904
M	0.001*	0.004*		0.002*
L	0.001*	0.904	0.002*	

C

Site	ANOVA/MANOVA $F_{3,36} = 7.45$; $p < 0.01$			
	D	C	M	L
D		0.201	0.004*	0.417
C	0.201		0.003*	0.999
M	0.004*	0.003*		0.007*
L	0.417	0.999	0.007*	

* Significant differences ($p < 0.05$).

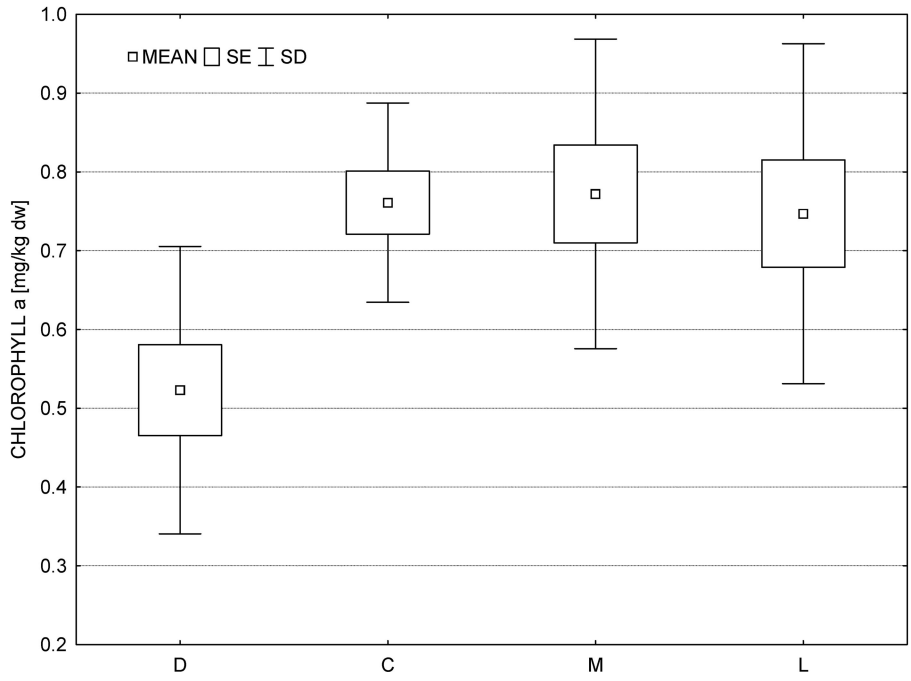


Fig. 7. Descriptive statistics of *B. pendula* leaf *chlorophyll a* concentrations for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

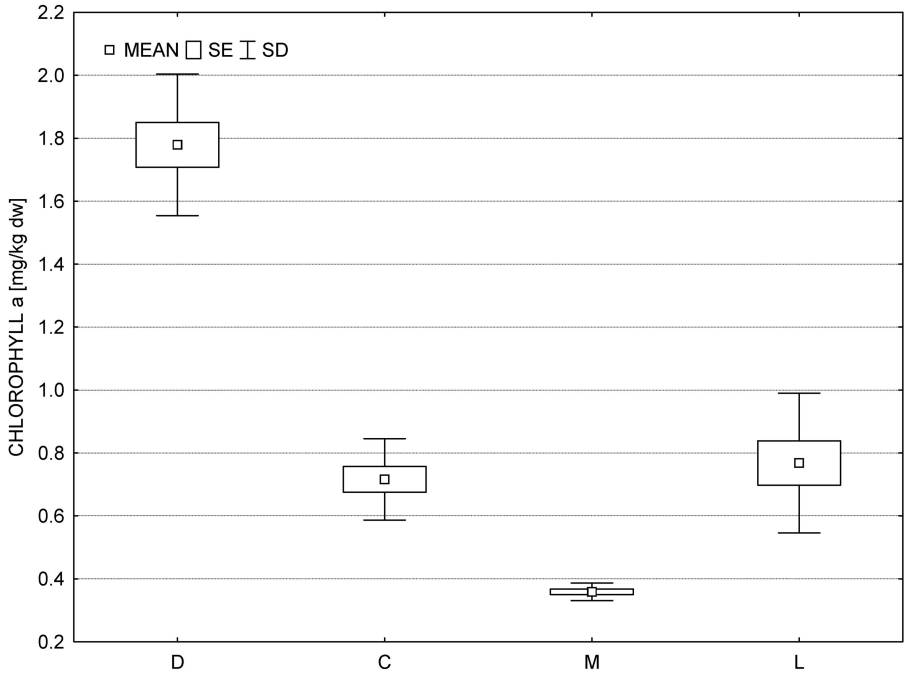


Fig. 8. Descriptive statistics of *B. pendula* leaf *chlorophyll a* concentrations for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

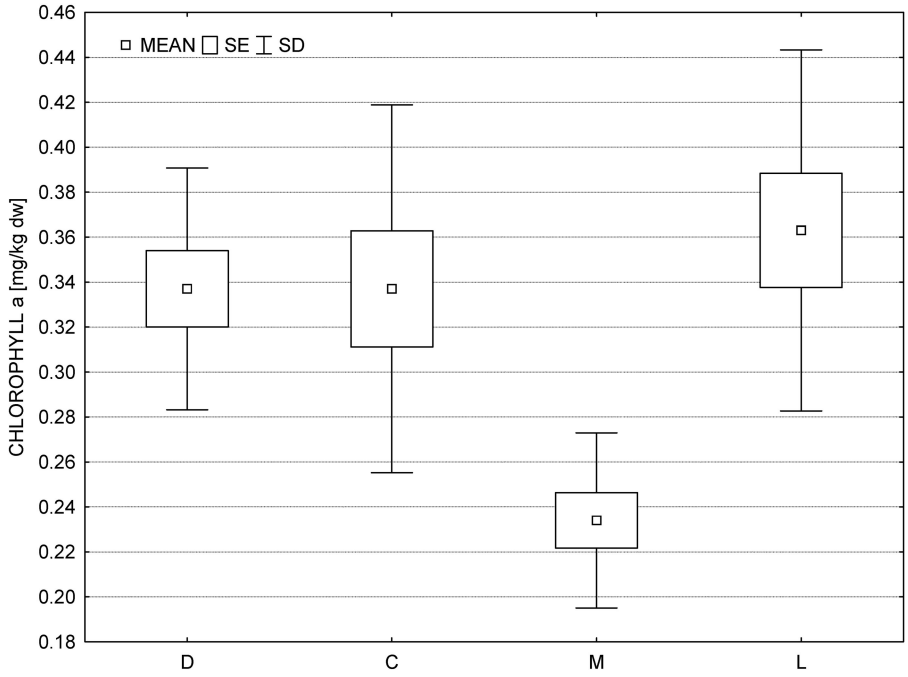


Fig. 9. Descriptive statistics of *B. pendula* leaf *chlorophyll a* concentrations for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The content of *chlorophyll b* in birch leaves

During the growing season of 2006, the lowest concentration of this pigment — 0.32 mg × kg^{-1} DW was recorded in leaves of trees from the zinc-lead dump, whereas the highest one — 0.48 mg × kg^{-1} DW for leaves of birch trees from Mirów (Table 2A). The T test revealed statistically significant differences between the zinc-lead dump and Mirów. Differences for other research sites were statistically insignificant (Fig. 10).

In 2007, the lowest concentration of *chlorophyll b* — 0.10 mg × kg^{-1} DW was recorded in leaves of birch specimens from Mirów, whereas the highest one — for leaves from the zinc-lead dump — 1.23 mg × kg^{-1} DW (Table 2B). The T test proved no significant differences between the mine waste dump and Łodygowice. Differences for other sites were statistically significant (Fig. 11).

In 2008, the content of *chlorophyll b* was the lowest one for leaves of birch specimens from the mine waste dump — 0.18 mg × kg^{-1} DW, and the highest one for leaves of trees from Mirów — 0.23 mg × kg^{-1} DW (Table 2C). The T test proved no significant differences between Mirów and mine waste dump. Differences for other sites were statistically significant (Fig. 12).

Table 2. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* chlorophyll b concentration for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 2.96$; $p < 0.01$			
	D	C	M	L
D		0.245	0.034*	0.162
C	0.245		0.778	0.995
M	0.034*	0.778		0.889
L	0.162	0.995	0.889	

B

Site	ANOVA/MANOVA $F_{3,36} = 150.93$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.003*	0.929
M	0.001*	0.003*		0.002*
L	0.001*	0.929	0.002*	

C

Site	ANOVA/MANOVA $F_{3,36} = 5.81$; $p < 0.01$			
	D	C	M	L
D		0.201*	0.241*	0.417*
C	0.201*		0.999	0.005*
M	0.241*	0.999		0.007*
L	0.417*	0.005*	0.007*	

* Significant differences ($p < 0.05$).

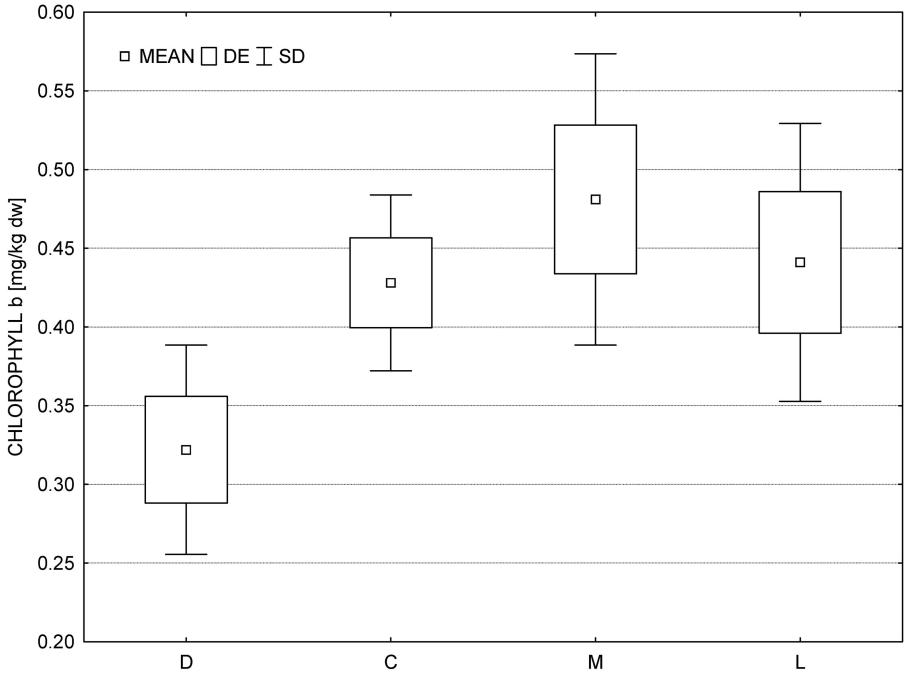


Fig. 10. Descriptive statistics of *B. pendula* leaf *chlorophyll b* concentrations for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

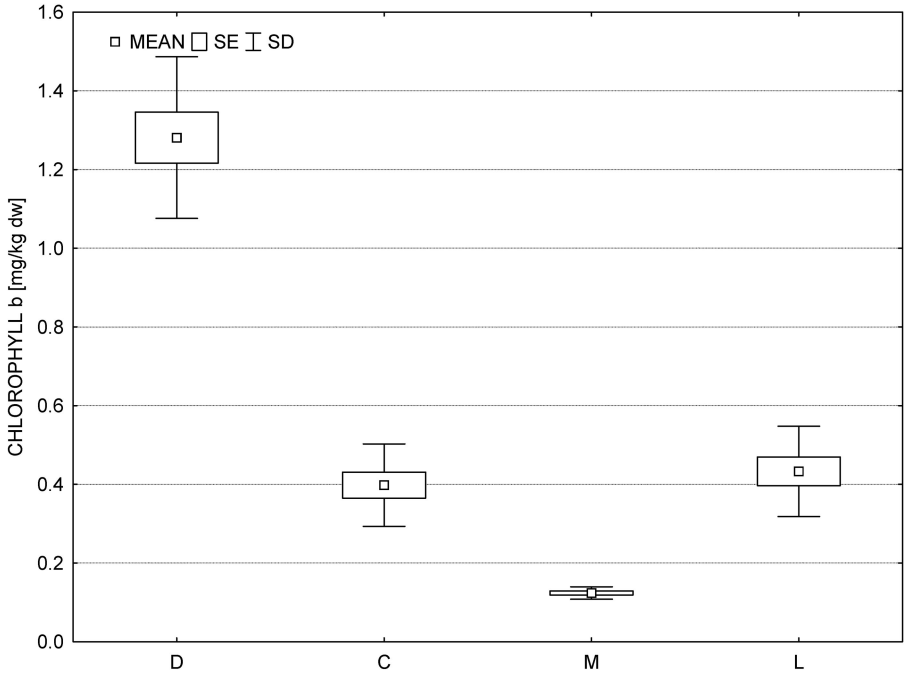


Fig. 11. Descriptive statistics of *B. pendula* leaf *chlorophyll b* concentrations for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

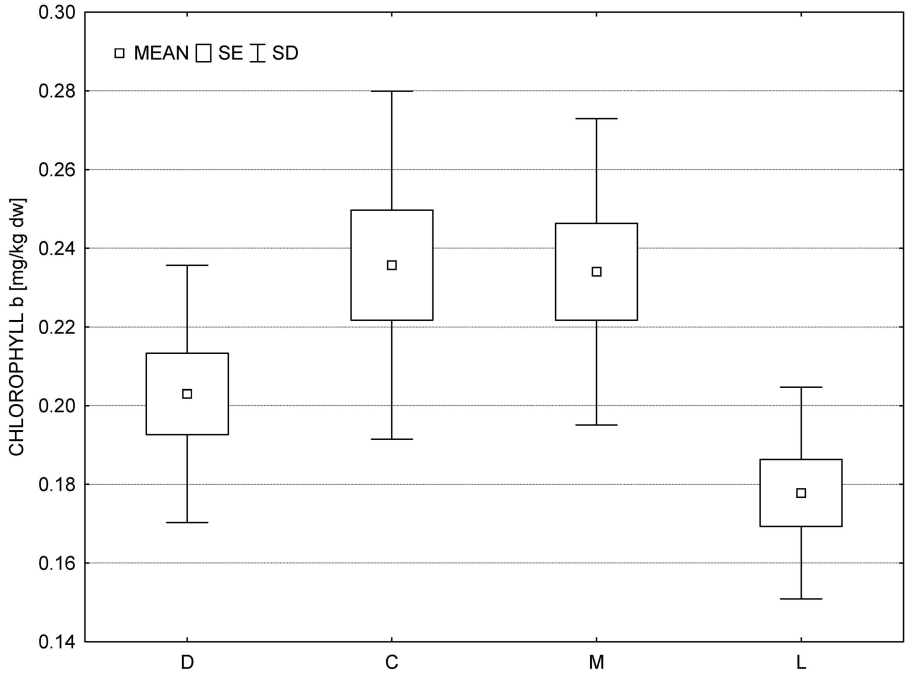


Fig. 12. Descriptive statistics of *B. pendula* leaf *chlorophyll b* concentrations for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The content of carotenoids in birch leaves

In 2006, the lowest concentration of carotenoids — 0.23 $mg \times kg^{-1}$ DW was recorded in the leaves of birch specimens coming from the zinc-lead dump, whereas the highest one — 0.81 $mg \times kg^{-1}$ DW in the leaves of trees growing in Mirów (Table 3A). The T test revealed significant differences only for the research site in Mirów (Fig. 13).

In the subsequent growing season of 2007, the lowest content of carotenoids — 0.14 $mg \times kg^{-1}$ DW was recorded in leaves of birch specimens coming from Mirów, and the highest one — 1.02 $mg \times kg^{-1}$ DW — in leaves of trees from the zinc-lead dump (Table 3B). The T test for this parameter revealed the significant differences only for the research sites located on the zinc-lead dump and in Mirów (Fig. 14).

In 2008, the lowest concentration of carotenoids — 0.13 $mg \times kg^{-1}$ DW was recorded in leaves of trees growing on the mine waste dump, and the highest one — 0.25 $mg \times kg^{-1}$ DW in leaves of birch specimens growing on the slag heap (Table 3C). The T test revealed significant differences between: the zinc-lead dump and the mine waste dump; Mirów and the mine waste dump; the zinc-lead dump and Łodygowice, as well as between Mirów and Łodygowice. For other pairs of the research sites, the differences turned out to be statistically insignificant (Fig. 15).

Table 3. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* carotenoids concentration ratio for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 13.86$; $p < 0.01$			
	D	C	M	L
D		0.811	0.001*	0.921
C	0.811		0.003*	0.994
M	0.001*	0.003*		0.002*
L	0.921	0.994	0.002*	

B

Site	ANOVA/MANOVA $F_{3,36} = 148.19$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.002*	0.747
M	0.001*	0.002*		0.032*
L	0.001*	0.747	0.032*	

C

Site	ANOVA/MANOVA $F_{3,36} = 22.48$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.116	0.001*
C	0.001*		0.002*	0.533
M	0.116	0.002*		0.004*
L	0.001*	0.533	0.004*	

* Significant differences ($p < 0.05$).

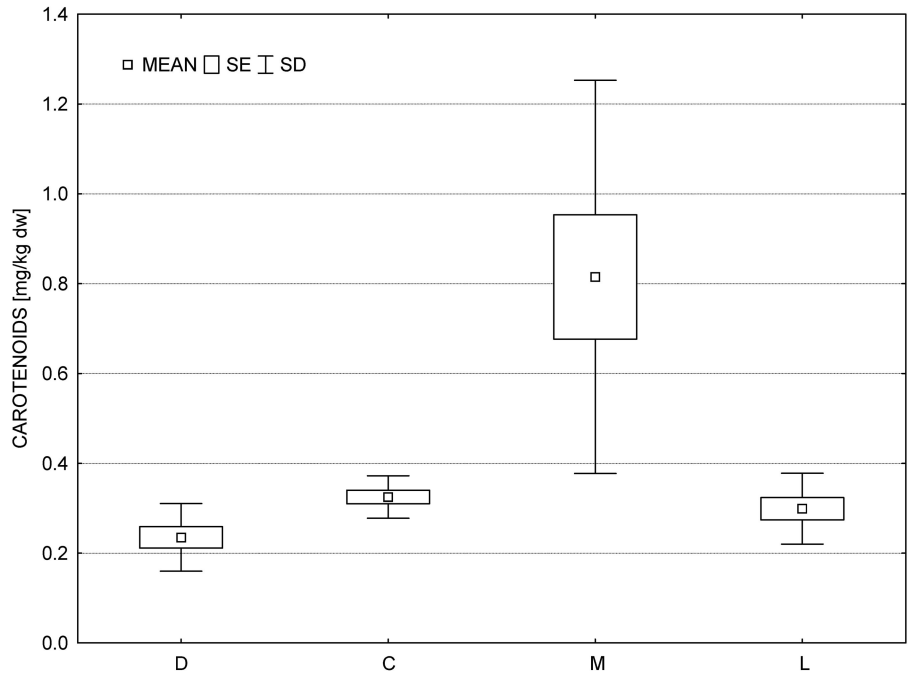


Fig. 13. Descriptive statistics of *B. pendula* leaf carotenoids concentrations for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

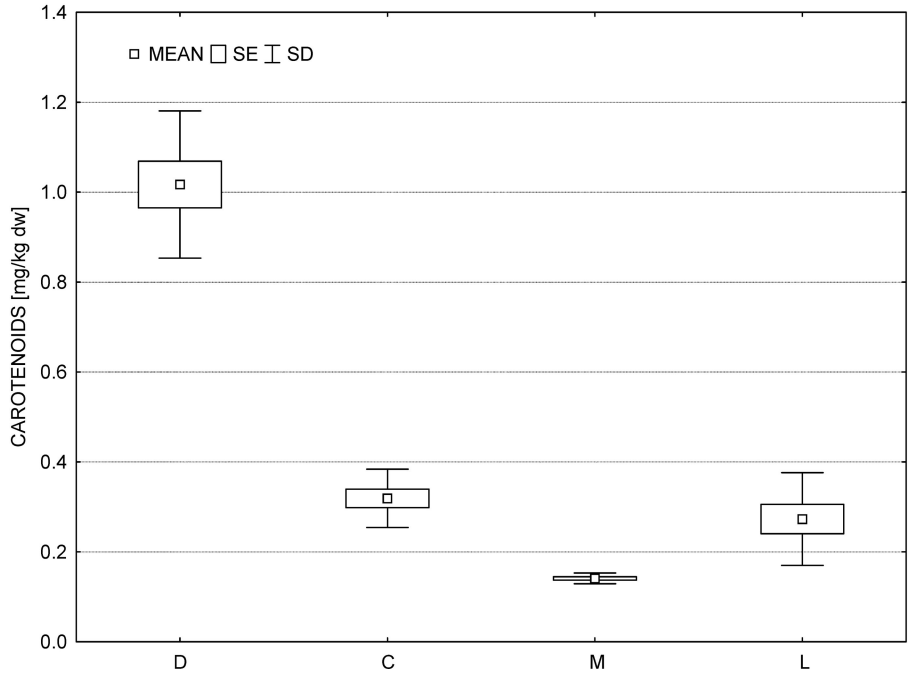


Fig. 14. Descriptive statistics of *B. pendula* leaf carotenoids concentrations for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

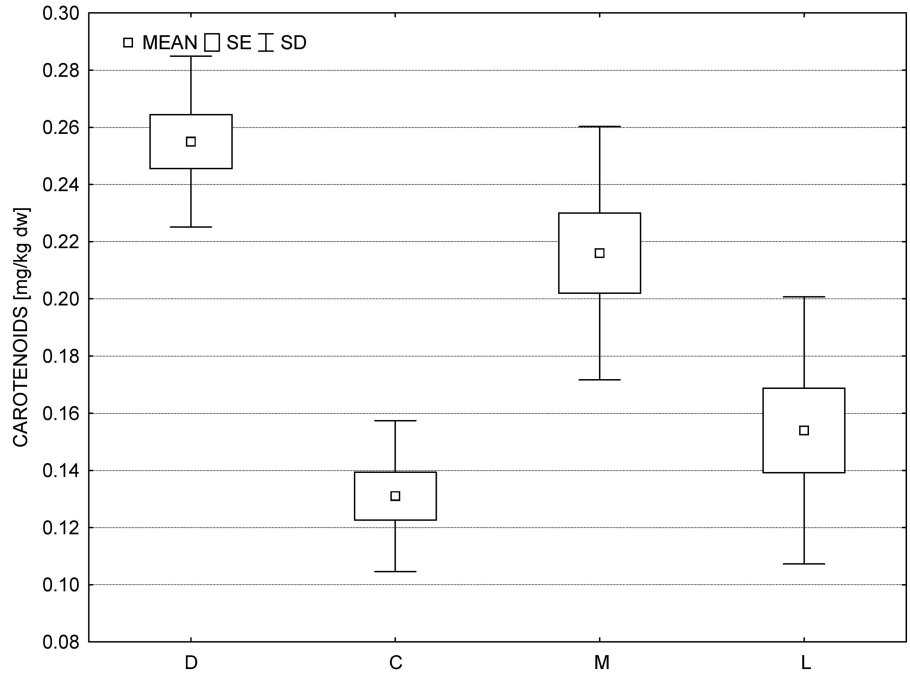


Fig. 15. Descriptive statistics of *B. pendula* leaf carotenoids concentrations for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The ratio of *chlorophyll a* to *chlorophyll b*

In the ecological research, the ratio of *chlorophyll a* to *chlorophyll b* is a useful parameter, because it is free of errors caused by different hydration of plant material, evaporation of solvent etc.

In 2006, the ratio of *chlorophyll a* to *chlorophyll b* had the lowest values for the research site located on the zinc-lead dump and amounted to 1.61, whereas the highest value of 1.80 was recorded for the research site at the mine waste dump (Table 4A). The T test for this parameter proved the significant differences only between the sites on the zinc-lead dump and the mine waste dump. For other research sites, the differences were statistically insignificant (Fig. 16).

In the subsequent growing season of 2007, the ratio of *chlorophyll a* to *chlorophyll b* was characterized by the lowest values — 1.41 — for the research site located on the zinc-lead dump, whereas the highest values — 2.95 — for the site located in Mirów (Table 4B). The T test revealed significant differences only for the research site in Mirów (Fig. 17).

In 2008, the ratio of *chlorophyll a* to *chlorophyll b* had the lowest values — 1.55 — for the research site located in Mirów, whereas the highest ones — 1.92 — for the site located on the mine waste dump (Table 4C). According to the T test, there are significant differences between the research zinc-lead dump and Łodygowice sites (Fig. 18).

Table 4. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* chlorophyll a/b concentration ratio for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 3.36$; $p < 0.01$			
	D	C	M	L
D		0.033*	0.976	0.381
C	0.033*		0.084	0.598
M	0.976	0.084		0.627
L	0.381	0.598	0.627	

B

Site	ANOVA/MANOVA $F_{3,36} = 16.67$; $p < 0.01$			
	D	C	M	L
D		0.113	0.0001*	0.364
C	0.113		0.0006*	0.908
M	0.0001*	0.0006*		0.0002*
L	0.364	0.908	0.0002*	

C

Site	ANOVA/MANOVA $F_{3,36} = 3.10$; $p < 0.01$			
	D	C	M	L
D		0.545	0.548	0.021*
C	0.545		1.000	0.3361
M	0.548	1.000		0.334
L	0.021*	0.336	0.334	

* Significant differences ($p < 0.05$).

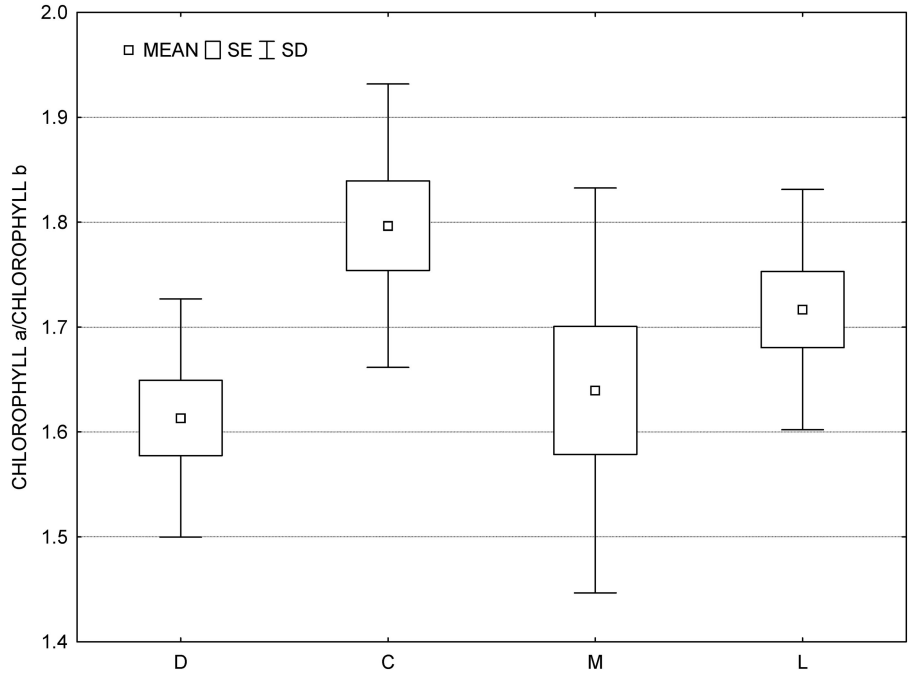


Fig. 16. Descriptive statistics of *B. pendula* leaf chlorophyll a/b ratio concentrations for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

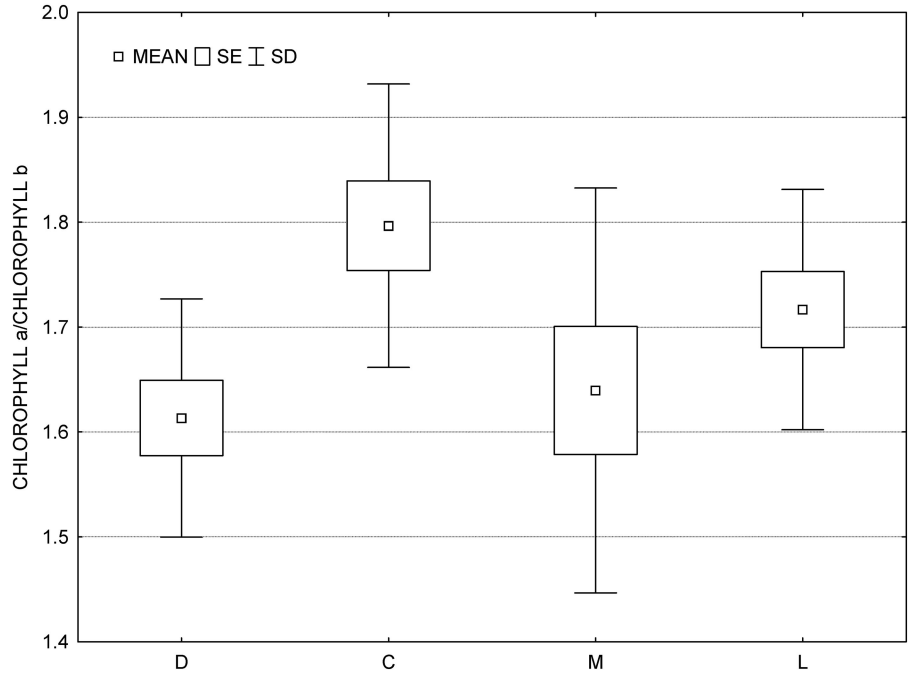


Fig. 17. Descriptive statistics of *B. pendula* leaf chlorophyll a/b ratio concentrations for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

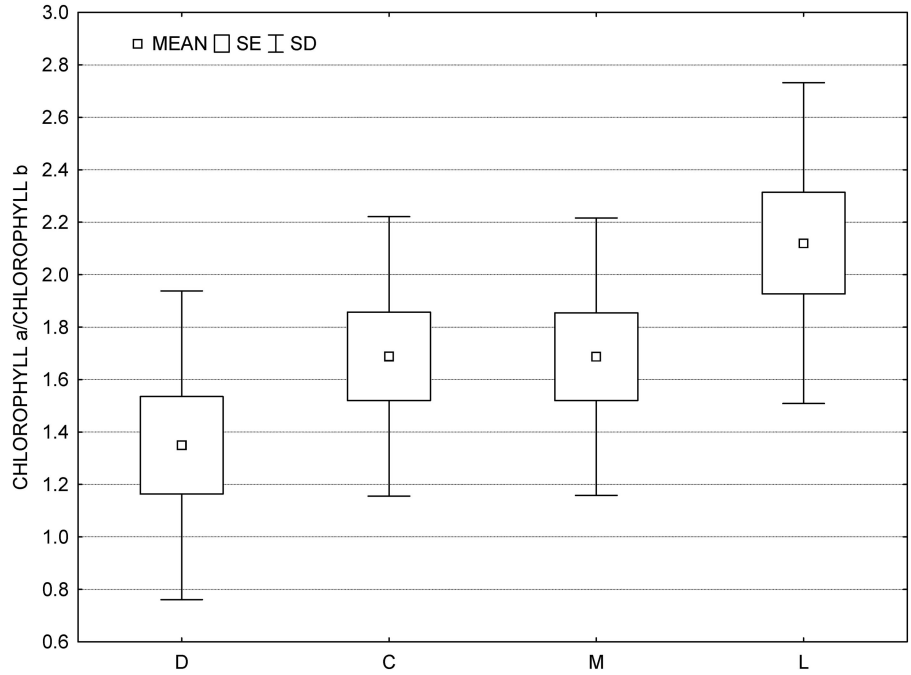


Fig. 18. Descriptive statistics of *B. pendula* leaf chlorophyll a/b ratio concentrations for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The number of birch leaves on selected twigs

During the three growing seasons, the smallest number of leaves — 240 — was recorded for trees growing on the zinc-lead dump, whereas the highest one on trees from Mirów — 511 leaves. Only in 2007, the highest number of leaves — 412 — was recorded for trees from Łodygowice. The number of leaves on trees growing in Mirów and Łodygowice was twice as high as the number of leaves on trees from the zinc-lead dump. The number of leaves from birch specimens on the mine waste dump was reduced by ca. 100—200 compared to trees from Łodygowice and Mirów. This tendency continued for all the growing seasons.

In 2006, the highest number of leaves was recorded for twigs of trees growing in Mirów — 511, the smallest one — on trees from the zinc-lead dump — 240 leaves (Table 5A). The T test revealed no significant differences between the zinc-lead dump and the mine waste dump. For other sites the differences were statistically significant (Fig. 19).

In the following growing season of 2007, the highest number of leaves was recorded for trees located in Łodygowice — 412, whereas the smallest one — for trees from the zinc-lead dump — 254 (Table 5B). The T test for this parameter revealed that there are no statistically significant differences between Mirów and Łodygowice sites. For the other research sites, the differences were statistically significant (Fig. 20).

In the growing season of 2008, the highest number of leaves was observed for trees from Mirów — 486, whereas the smallest one — for trees growing on the zinc-lead dump — 249 leaves (Table 5C). The T test revealed significant differences for all research sites (Fig. 21).

Table 5. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* leaves number for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 22.48$; $p < 0.01$			
	D	C	M	L
D		0.001	0.116*	0.001*
C	0.001		0.002*	0.533*
M	0.116*	0.002*		0.004*
L	0.001*	0.533*	0.004*	

B

Site	ANOVA/MANOVA $F_{3,36} = 17.64$; $p < 0.01$			
	D	C	M	L
D		0.193*	0.002*	0.001*
C	0.193*		0.008*	0.007*
M	0.002*	0.008*		0.791
L	0.001*	0.007*	0.791	

C

Site	ANOVA/MANOVA $F_{3,36} = 42.37$; $p < 0.01$			
	D	C	M	L
D		0.006*	0.001*	0.001*
C	0.006*		0.001*	0.003*
M	0.001*	0.001*		0.011*
L	0.001*	0.003*	0.011*	

* Significant differences ($p < 0.05$).

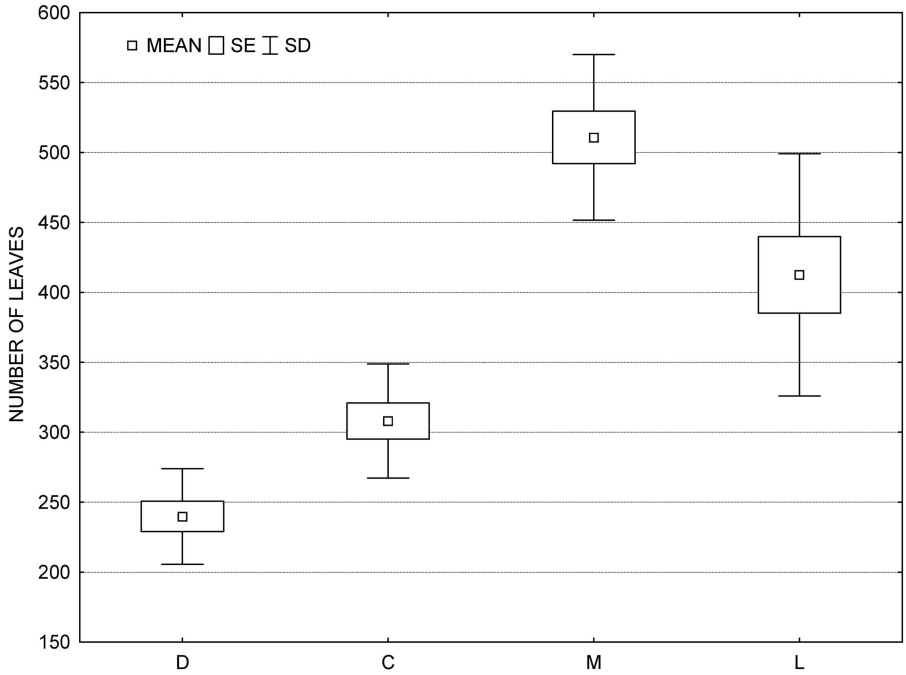


Fig. 19. Descriptive statistics of *B. pendula* leaf number for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

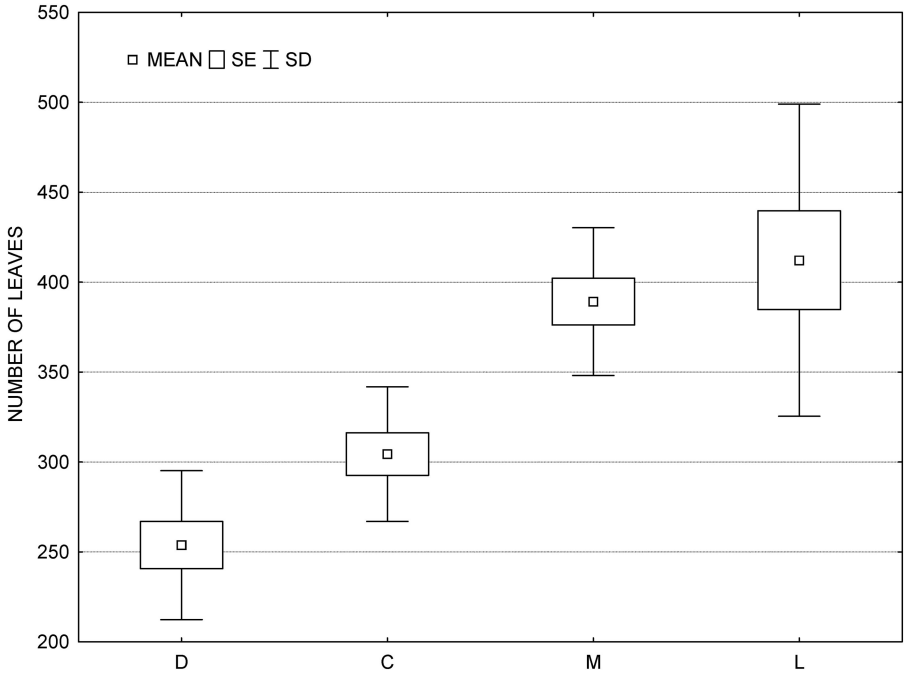


Fig. 20. Descriptive statistics of *B. pendula* leaf number for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

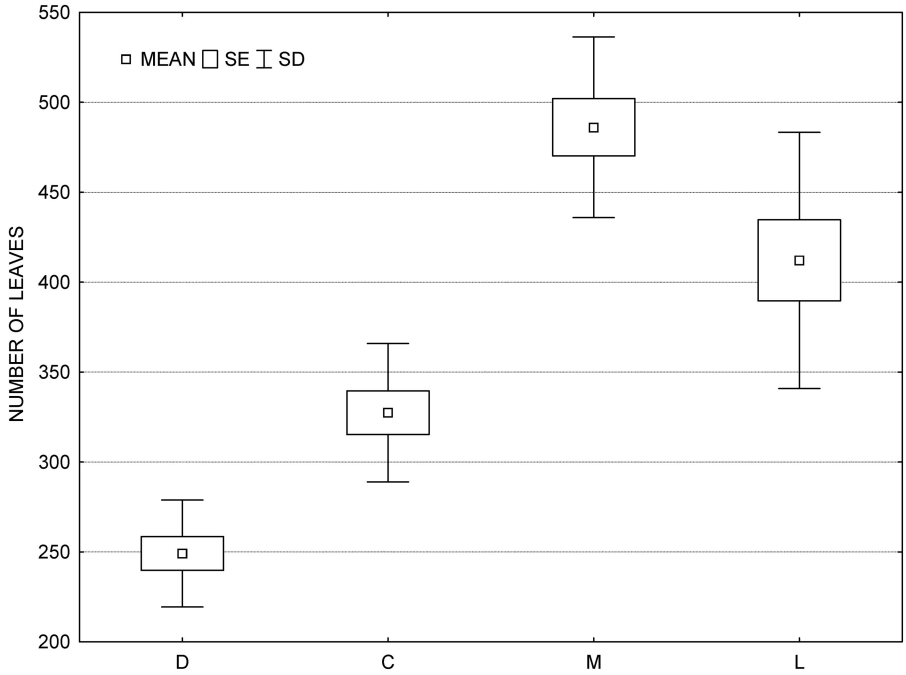


Fig. 21. Descriptive statistics of *B. pendula* leaf number for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The surface area of a lamina

Trees from Łodygowice were characterized by the largest surface area of a lamina — 10.48 cm^2, and laminae of birch specimens growing on the zinc-lead dump were three times smaller — 3.32 cm^2. The laminae of birch specimens from the mine waste dump and the zinc-lead dump, as well as from Mirów, were comparable with each other. These tendencies were observed for the subsequently studied growing seasons.

In 2006, the largest surface area of a lamina was recorded for birch specimens growing in Łodygowice — 10.48 cm^2, and the smallest one for trees from the zinc-lead dump — 4.34 cm^2 (Table 6A). The T test revealed that differences for all research studied sites were significant (Fig. 22).

In the subsequent growing season of 2007, trees from Łodygowice had the largest surface area of leaves — 10.09 cm^2, and trees from the zinc-lead dump — the smallest one — 3.32 cm^2 (Table 6B). The T test revealed significant differences for all research sites (Fig. 23).

In 2008, the largest surface area of a lamina was recorded for trees growing in Łodygowice — 10.35 cm^2, and the smallest one for birch specimens from the zinc-lead dump — 4.56 cm^2 (Table 6C). The statistical analysis revealed the lack of significant differences only between the mine waste dump and Mirów. For other research sites, the differences were statistically significant (Fig. 24).

Table 6. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* lamina surface area for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 933.57$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

B

Site	ANOVA/MANOVA $F_{3,36} = 690.44$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.008*	0.001*
M	0.001*	0.008*		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 525.07$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.109	0.001*
M	0.001*	0.109		0.001*
L	0.001*	0.001*	0.001*	

* Significant differences ($p < 0.05$).

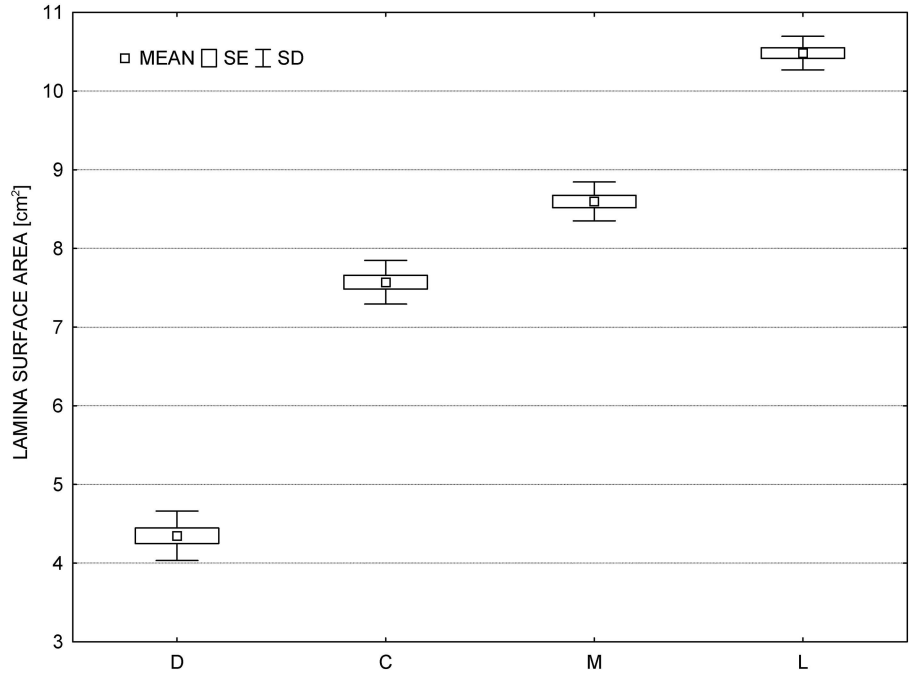


Fig. 22. Descriptive statistics of *B. pendula* lamina surface area for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

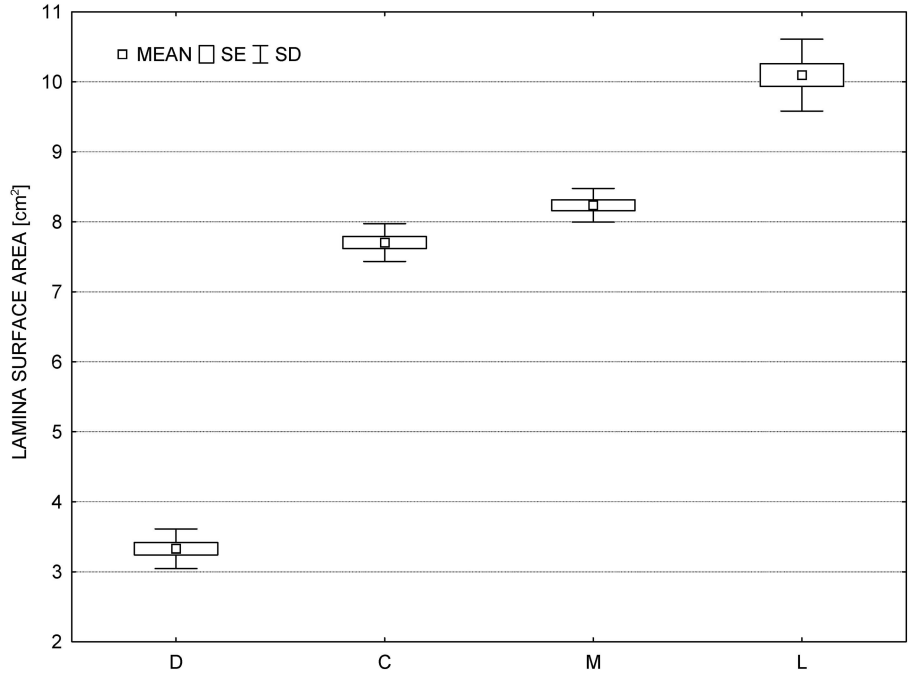


Fig. 23. Descriptive statistics of *B. pendula* lamina surface area for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

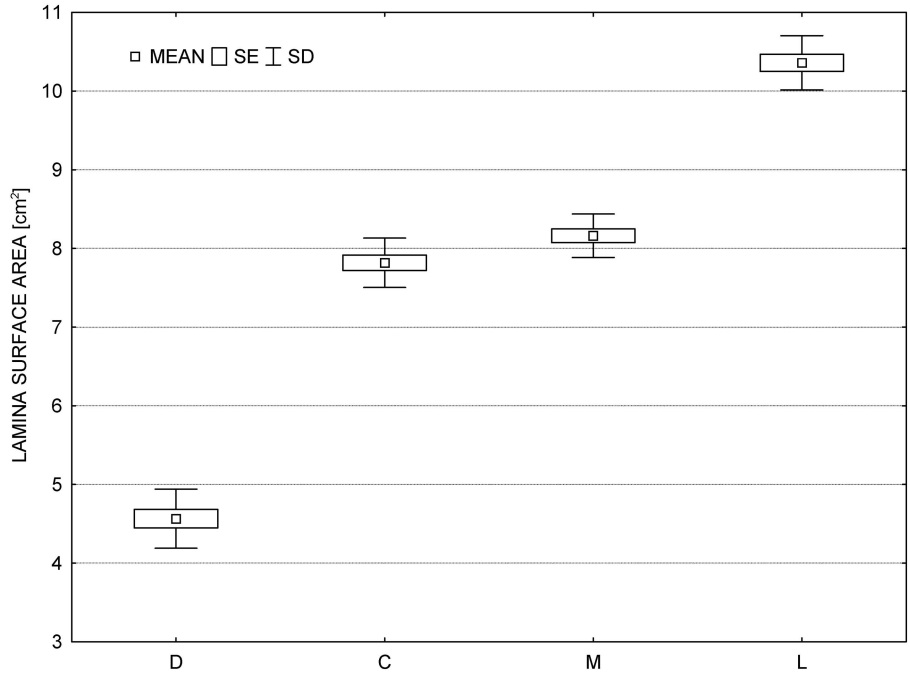


Fig. 24. Descriptive statistics of *B. pendula* lamina surface area for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

Biometric characteristics of generative organs

The number of staminate inflorescences

During the three growing seasons, the smallest number of staminate inflorescences — 20 — was recorded for trees growing on the zinc-lead dump, whereas the highest one for trees from the mine waste dump — 60. The number of staminate inflorescences on trees growing on the mine waste dump was twice, and in 2008 three times higher as compared with trees from the zinc-lead dump. This tendency continued for all the research years.

In 2006, the smallest number of staminate inflorescences — 33 — was recorded for trees from the zinc-lead dump, whereas the highest one — 54 — for birch specimens growing on the mine waste dump (Table 7A). The T test revealed significant differences for the research site located on the mine waste dump, as well as between the zinc-lead dump and Mirów. For other sites, the differences were statistically insignificant (Fig. 25).

In the successive growing season of 2007, the smallest number of staminate inflorescences — 33 — was recorded for trees growing on the zinc-lead dump, whereas the highest one — 60 — for birch trees growing on the mine waste dump (Table 7B). The T test revealed statistically significant differences only for the research sites located on the zinc-lead and mine waste dumps. For other sites, the differences were statistically insignificant (Fig. 26).

In 2008, the smallest number of staminate inflorescences — 20 — was recorded for birch trees from the zinc-lead dump, whereas the highest one — 60 — for trees from the mine waste dump (Table 7C). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and the mine waste dump. For the other research sites, the differences were statistically insignificant (Fig. 27).

Table 7. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* number of staminate inflorescence for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 17.96$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.025*	0.307
C	0.001*		0.001*	0.001*
M	0.025*	0.001*		0.624
L	0.307	0.001*	0.624	

B

Site	ANOVA/MANOVA $F_{3,36} = 31.92$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.008*	0.003*
C	0.001*		0.001*	0.002*
M	0.008*	0.001*		0.963
L	0.003*	0.002*	0.963	

C

Site	ANOVA/MANOVA $F_{3,36} = 100.19$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.003*
M	0.001*	0.001*		0.921
L	0.001*	0.003*	0.921	

* Significant differences ($p < 0.05$).

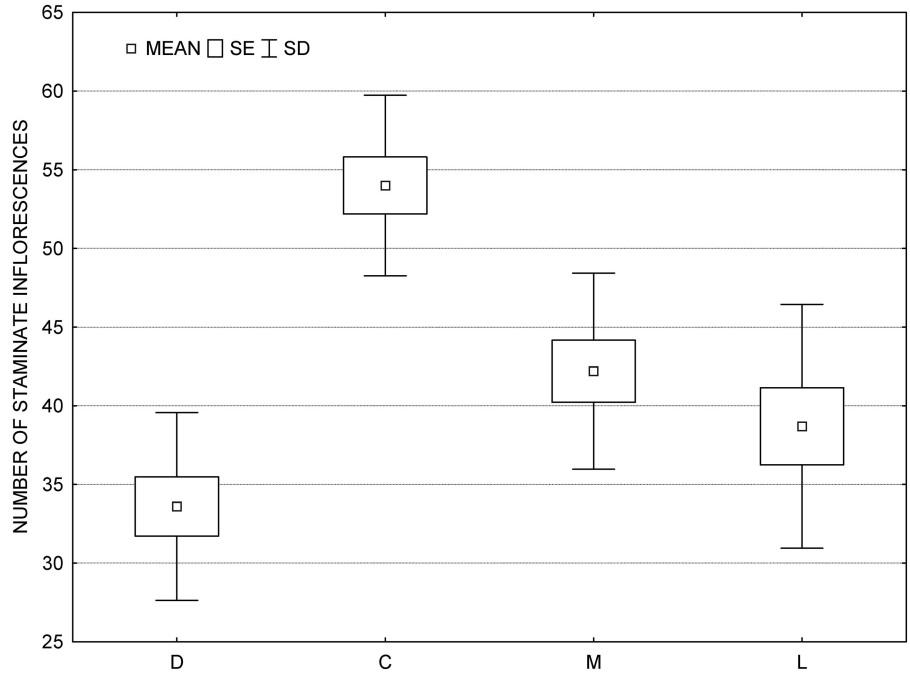


Fig. 25. Descriptive statistics of *B. pendula* number of staminate inflorescence for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

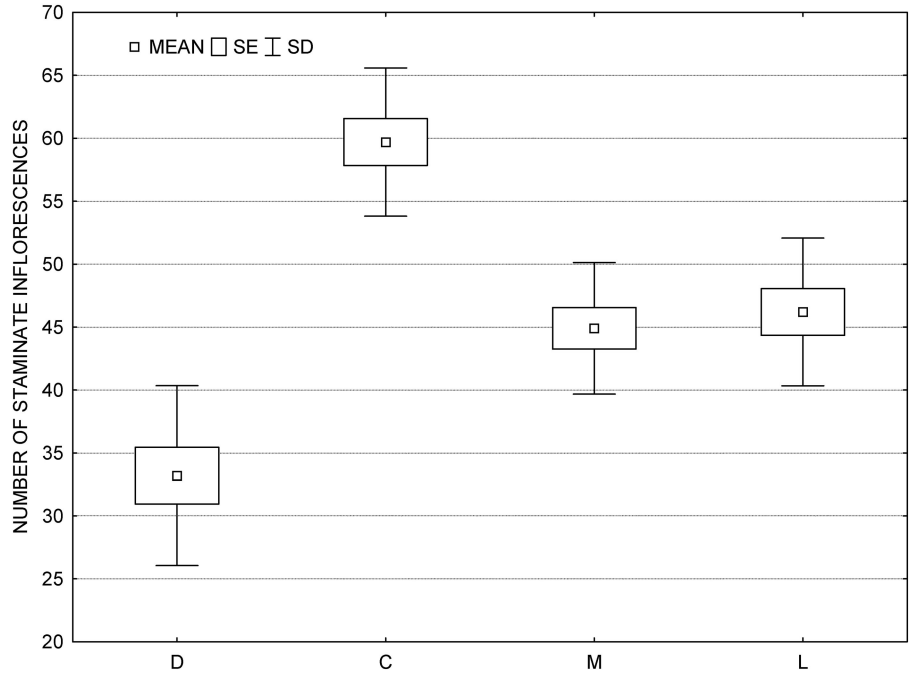


Fig. 26. Descriptive statistics of *B. pendula* number of staminate inflorescence for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

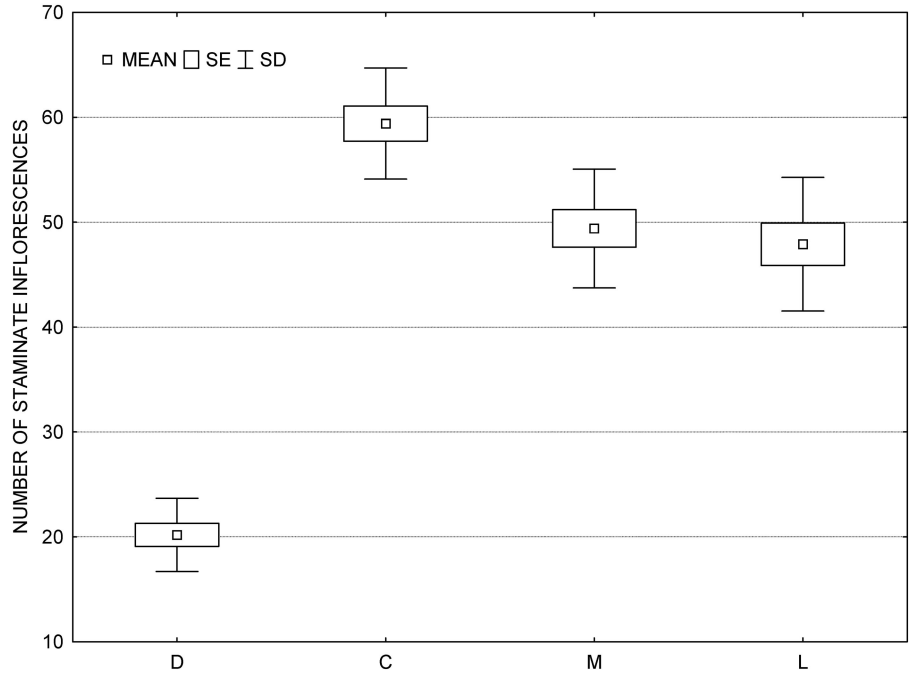


Fig. 27. Descriptive statistics of *B. pendula* number of staminate inflorescence for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The number of pistillate inflorescences

During the three research years, the smallest number of pistillate inflorescences was recorded for trees growing on the zinc-lead dump — 16, whereas the highest one — 54 — for trees from Łodygowice. The number of pistillate inflorescences on birch specimens growing in Łodygowice was twice, and in 2008 three times higher as compared with trees from the zinc-lead dump. This tendency continued during all the growing seasons.

In 2006, the smallest number of pistillate inflorescences — 18 — was recorded for birch specimens from the zinc-lead dump, and the highest one — 47 — for trees from Łodygowice (Table 8A). The T test revealed significant differences for all research sites (Fig. 28).

In the subsequent research season of 2007, the smallest number of pistillate inflorescences — 21 — was recorded for trees growing on the zinc-lead dump, and the highest one — 50 —for birch specimens from Łodygowice (Table 8B). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and in Łodygowice. For the other research sites, these differences were insignificant (Fig. 29).

In 2008, the smallest number —16 — of pistillate inflorescences was recorded for trees growing on the zinc-lead dump, and the highest one — 54 — for birch specimens from Łodygowice (Table 8C). The T test proved statistically significant differences only between research sites located on the zinc-lead dump and in Łodygowice. For other sites, no statistically significant differences were recorded (Fig. 30).

Table 8. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* number of pistillate inflorescence for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 53.14$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.003*	0.001*
C	0.001*		0.001*	0.021*
M	0.003*	0.001*		0.001*
L	0.001*	0.021*	0.001*	

B

Site	ANOVA/MANOVA $F_{3,36} = 36.46$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.897	0.005*
M	0.001*	0.897		0.007*
L	0.001*	0.005*	0.007*	

C

Site	ANOVA/MANOVA $F_{3,36} = 99.46$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.992	0.001*
M	0.001*	0.992		0.001*
L	0.001*	0.001*	0.001*	

* Significant differences ($p < 0.05$).

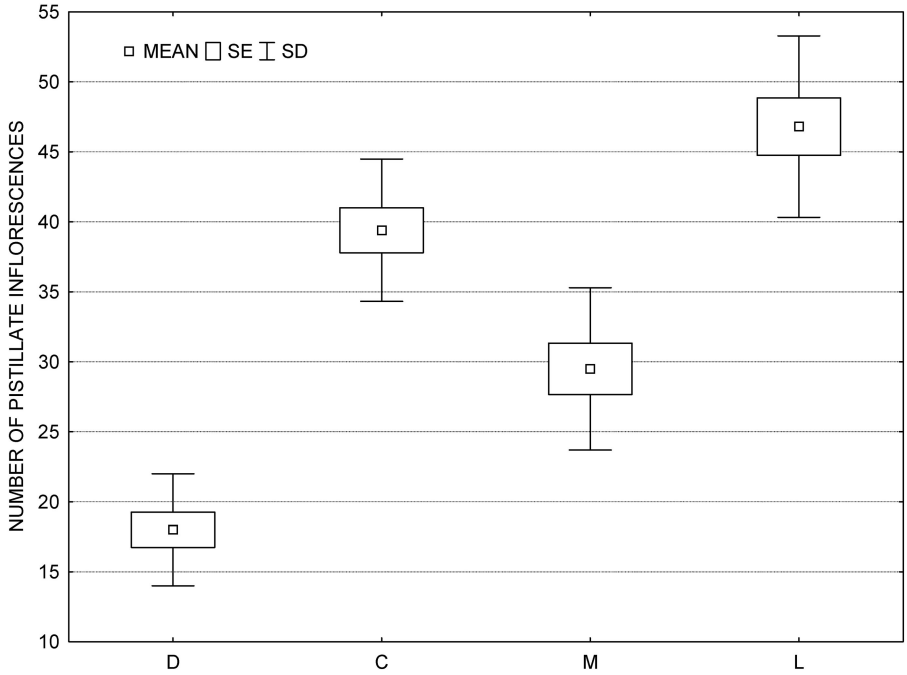


Fig. 28. Descriptive statistics of *B. pendula* number of pistillate inflorescence for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

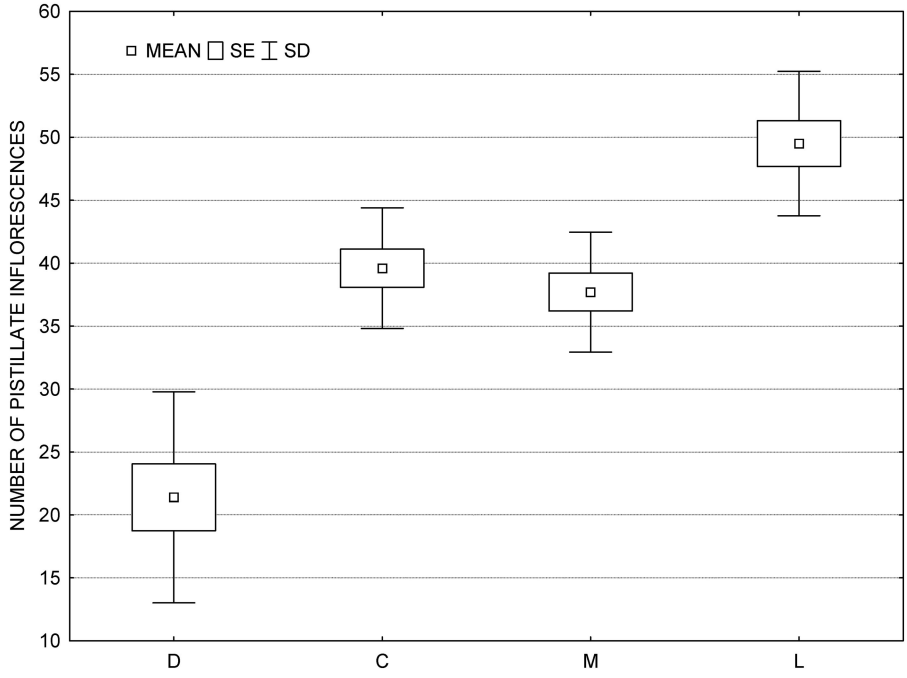


Fig. 29. Descriptive statistics of *B. pendula* number of pistillate inflorescence for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

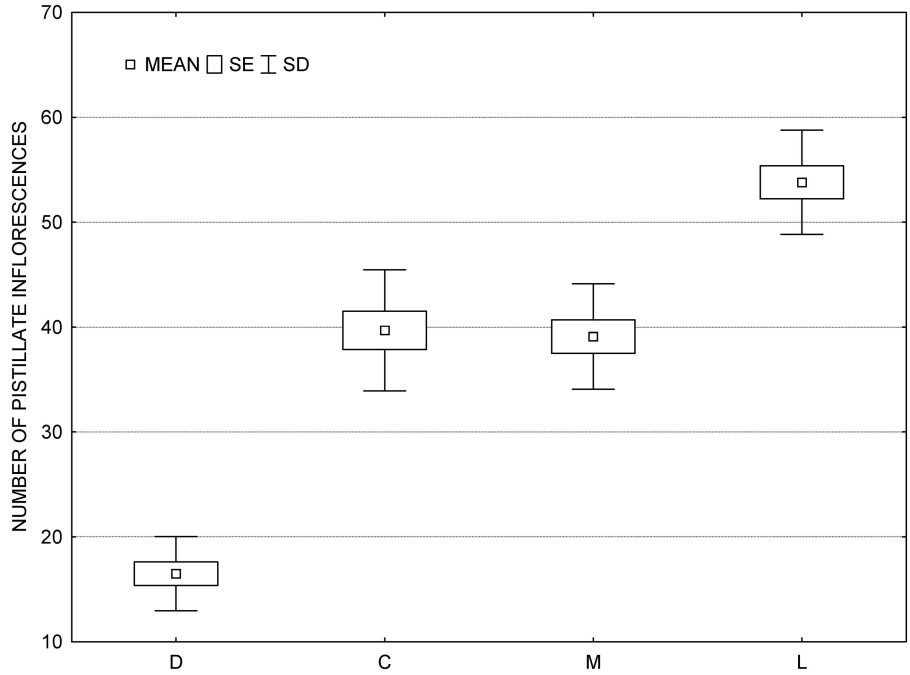


Fig. 30. Descriptive statistics of *B. pendula* number of pistillate inflorescence for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The length of staminate inflorescences

During the three growing seasons, the maximum length of staminate inflorescences — 3.21 cm — was recorded for birch specimens growing in Łodygowice. In 2007 and 2008, trees from the research sites in Łodygowice and the mine waste dump were characterized by a similar length of staminate inflorescences — ca. 3 cm, whereas their minimum length — 1.80 cm — was recorded for trees from the zinc-lead dump and this tendency stayed throughout the subsequent research seasons.

In 2006, the minimum length of staminate inflorescences — 2.19 cm — was recorded for birch specimens growing on the zinc-lead dump, whereas the maximum length — 3.21 cm — for trees from Łodygowice (Table 9A). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and in Łodygowice. For other sites, the differences were statistically insignificant (Fig. 31).

In the subsequent research season of 2007, the minimum length of staminate inflorescences — 1.90 cm — was recorded for trees growing on the zinc-lead dump, and the maximum length — 3.01 and 2.99 cm — for birch trees from the mine waste dump and Łodygowice (Table 9B). The T test revealed significant differences only for the research sites located on the zinc-lead dump and in Mirów. For other sites, the differences were statistically insignificant (Fig. 32).

In 2008, the minimum length of staminate inflorescences — 1.87 cm — was recorded for birch trees from the zinc-lead dump, whereas the maximum length — 2.98 and 2.95 cm —for trees from the mine waste dump and Łodygowice (Table 9C). The T test revealed significant differences only for the research sites located on the zinc-lead dump and in Mirów (Fig. 33).

Table 9. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendul*a lenght of staminate inflorescence for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 41.19$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.827	0.002*
M	0.001*	0.827		0.024*
L	0.001*	0.002*	0.024*	

B

Site	ANOVA/MANOVA $F_{3,36} = 142.03$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.993
M	0.001*	0.001*		0.001*
L	0.001*	0.993	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 365.48$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.914
M	0.001*	0.001*		0.001*
L	0.001*	0.914	0.001*	

* Significant differences ($p < 0.05$).

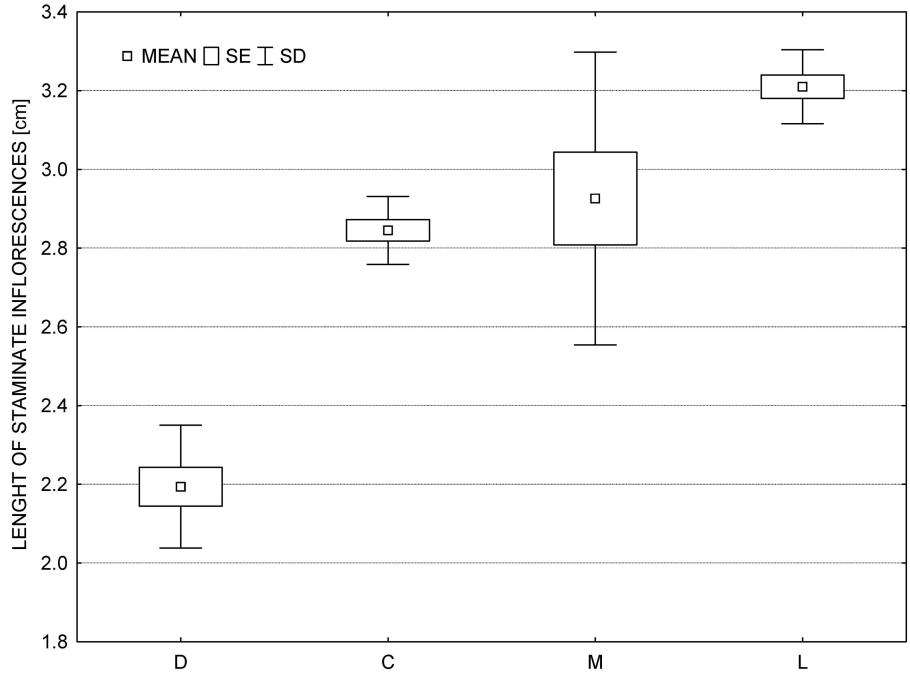


Fig. 31. Descriptive statistics of *B. pendula* length of staminate inflorescences for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

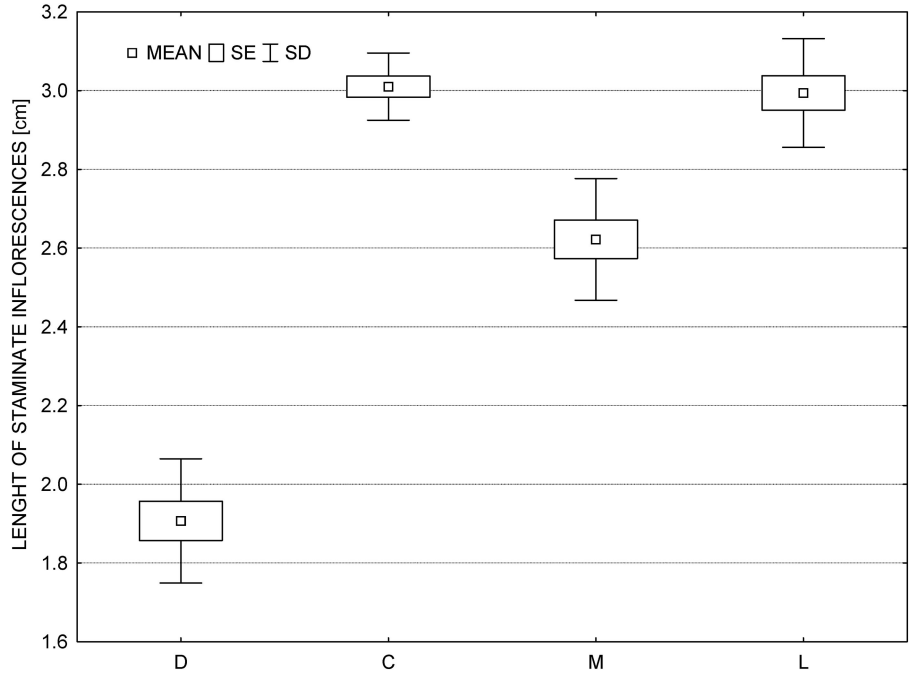


Fig. 32. Descriptive statistics of *B. pendula* length of staminate inflorescences for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

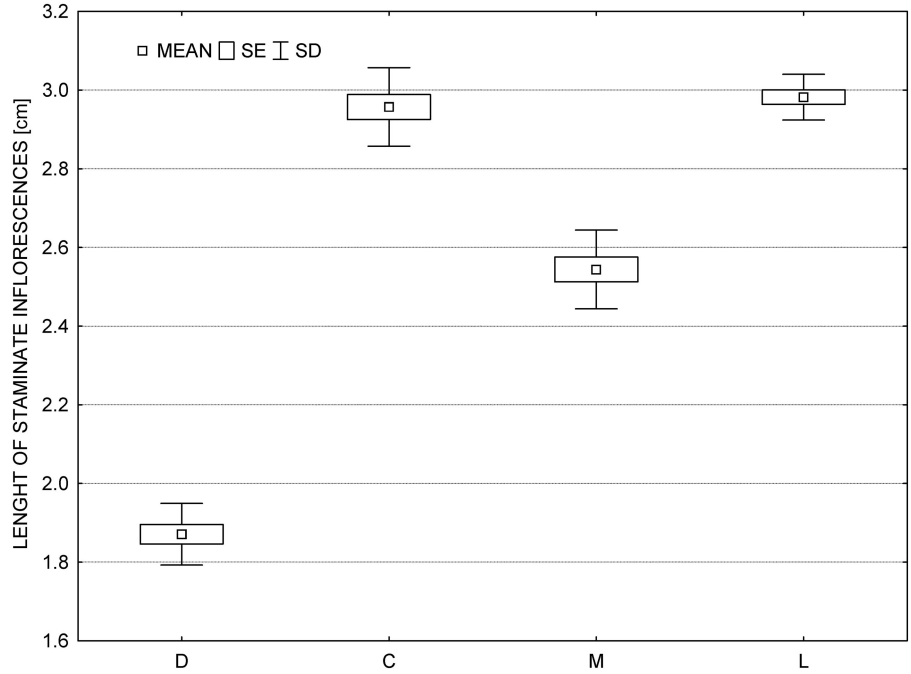


Fig. 33. Descriptive statistics of *B. pendula* length of staminate inflorescences for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The length of pistillate inflorescences

During the three growing seasons, the longest pistillate inflorescences — 2.88 cm — were recorded for trees from Mirów, whereas the shortest ones — 1.90 cm — for birch trees growing in Łodygowice. Only in 2006, the minimum length of pistillate inflorescences — 2.32 cm was recorded for birch trees located on the zinc-lead dump.

In 2006, the shortest pistillate inflorescences — 2.32 cm — were recorded for birch trees from the zinc-lead dump, and the longest ones — 2.80 cm — for trees growing in Mirów (Table 10A). The T test revealed significant differences only between Mirów and the zinc-lead and mine waste dumps, as well as between the slag dump and Łodygowice. For the other research sites, the differences were statistically insignificant (Fig. 34).

In the subsequent growing season of 2007, the minimum length of pistillate inflorescences — 1.92 cm — was recorded for birch trees growing in Łodygowice, and the maximum length for trees from Mirów — 2.88 cm (Table 10B). The T test revealed statistically significant differences for all research sites (Fig. 35).

In 2008, the minimum length of pistillate inflorescences was recorded for birch trees growing in Łodygowice — 2.17 cm, whereas the maximum length for trees from Mirów — 2.75 cm (Table 10C). The T test revealed no significant differences between the zinc-lead dump and Łodygowice. For the other research sites, the differences were significant (Fig. 36).

Table 10. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* length of pistillate inflorescence for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 9.99$; $p < 0.01$			
	D	C	M	L
D		0.695	0.003*	0.005*
C	0.695		0.003*	0.071
M	0.003*	0.003*		0.614
L	0.005*	0.071	0.614	

B

Site	ANOVA/MANOVA $F_{3,36} = 77.42$; $p < 0.01$			
	D	C	M	L
D		0.006*	0.001*	0.001*
C	0.006*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 86.86$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.089
C	0.001*		0.003*	0.001*
M	0.001*	0.003*		0.001*
L	0.089	0.001*	0.001*	

* Significant differences ($p < 0.05$).

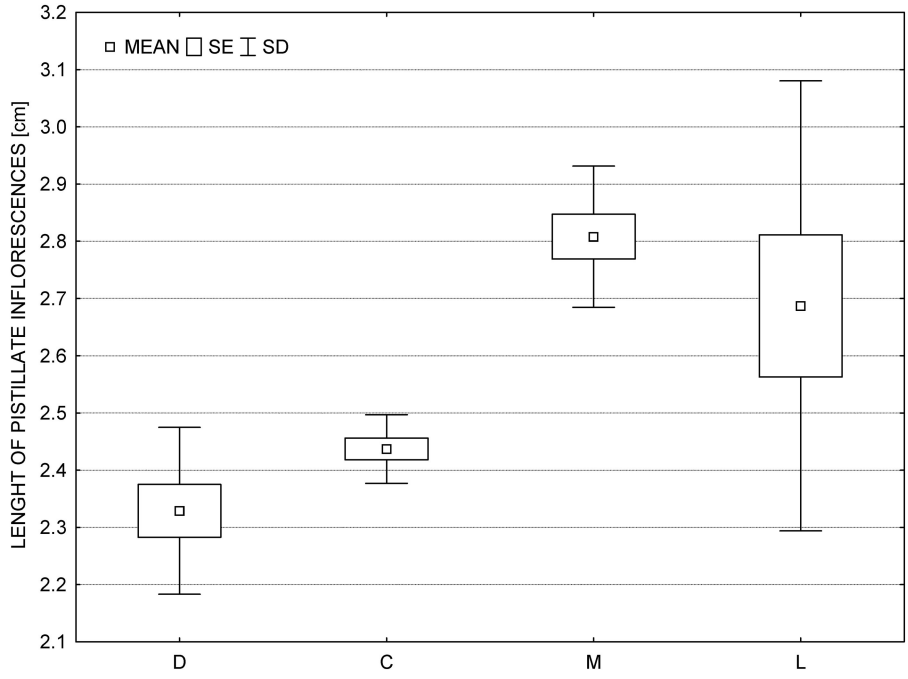


Fig. 34. Descriptive statistics of *B. pendula* length of pistillate inflorescence for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

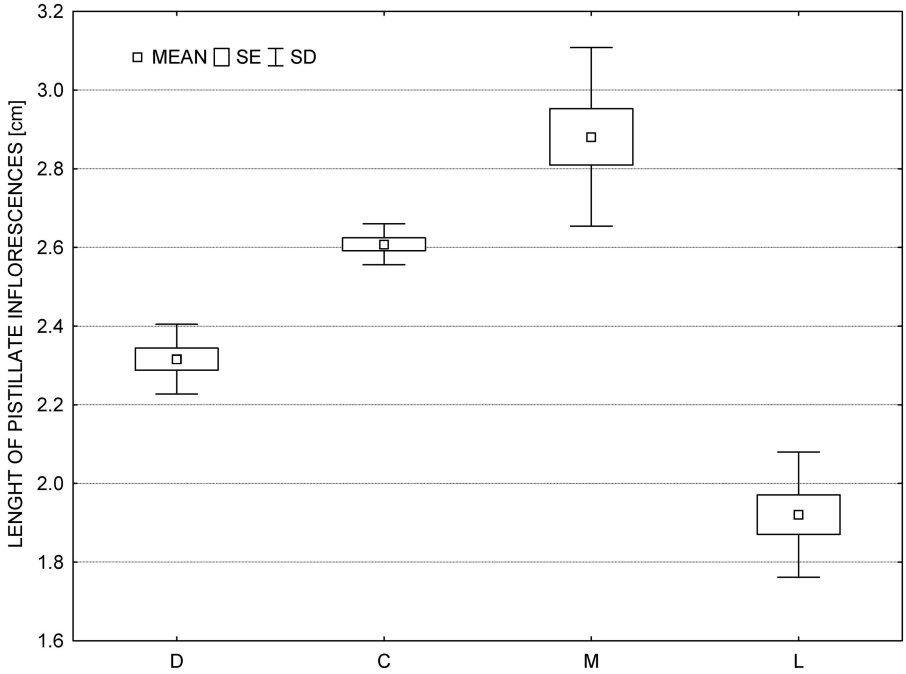


Fig. 35. Descriptive statistics of *B. pendula* length of pistillate inflorescence for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

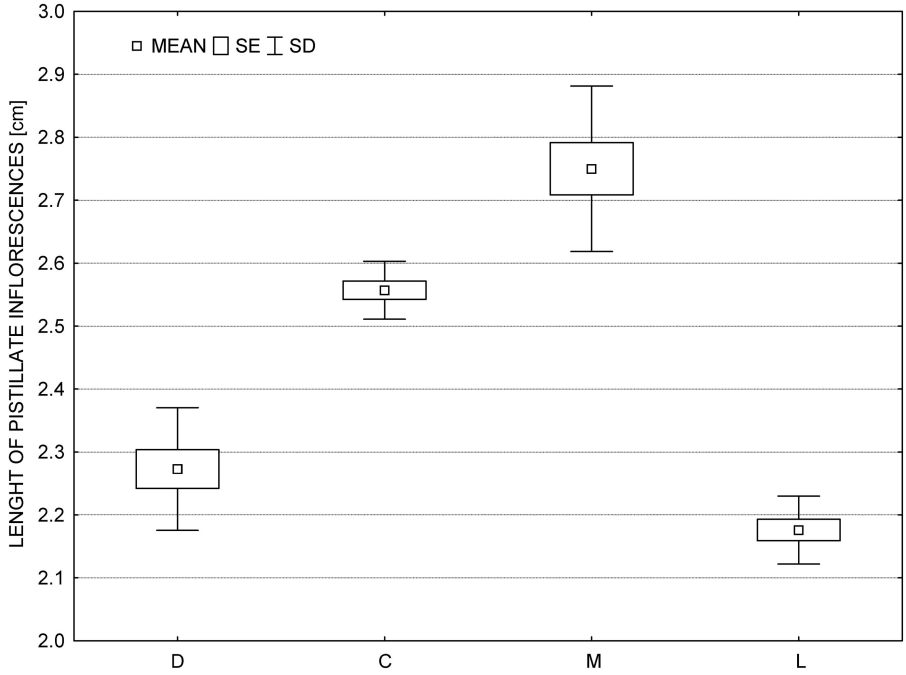


Fig. 36. Descriptive statistics of *B. pendula* length of pistillate inflorescence for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The length of fructification axes

During the three growing seasons, the minimum length of fructification axes — 1.89 cm — was recorded for birch trees growing on the zinc-lead dump, whereas their maximum length of 4.42 cm — was recorded for trees from Łodygowice. This tendency continued during all years of this research.

In 2006, birch trees growing on the zinc-lead dump were characterized by the shortest axis of fructifications — 1.95 cm, whereas trees from Łodygowice — by the longest one — 4.42 cm (Table 11A). The T test revealed significant differences only for the research sites located on the zinc-lead dump and in Łodygowice (Fig. 37).

In the successive growing season of 2007, the minimum length of fructification axes — 1.89 cm — was recorded for trees from the zinc-lead dump, whereas the maximum length of 4.23 cm — for birch trees from Łodygowice (Table 11B). The T test revealed statistically significant differences only for the research sites located in Łodygowice and on the zinc-lead dump (Fig. 38).

During the growing season of 2008, the shortest axis of fructifications — 2.04 cm — was recorded for trees growing on the zinc-lead dump, whereas the longest one of 4.39 cm — for trees from Łodygowice (Table 11C). The T test revealed that statistically significant differences occur only for the research sites located in Łodygowice and on the zinc-lead dump. For other sites, the differences were statistically insignificant (Fig. 39).

Table 11. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* length of fructification axes for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 561.36$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.737	0.001*
M	0.001*	0.737		0.001*
L	0.001*	0.001*	0.001*	

B

Site	ANOVA/MANOVA $F_{3,36} = 806.07$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.414	0.001*
M	0.001*	0.414		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 594.31$; $p < 0.01$			
	D	C	M	L
D		0.0001*	0.0001*	0.0001*
C	0.0001*		0.999	0.0001*
M	0.0001*	0.999		0.0001*
L	0.0001*	0.0001*	0.0001*	

* Significant differences ($p < 0.05$).

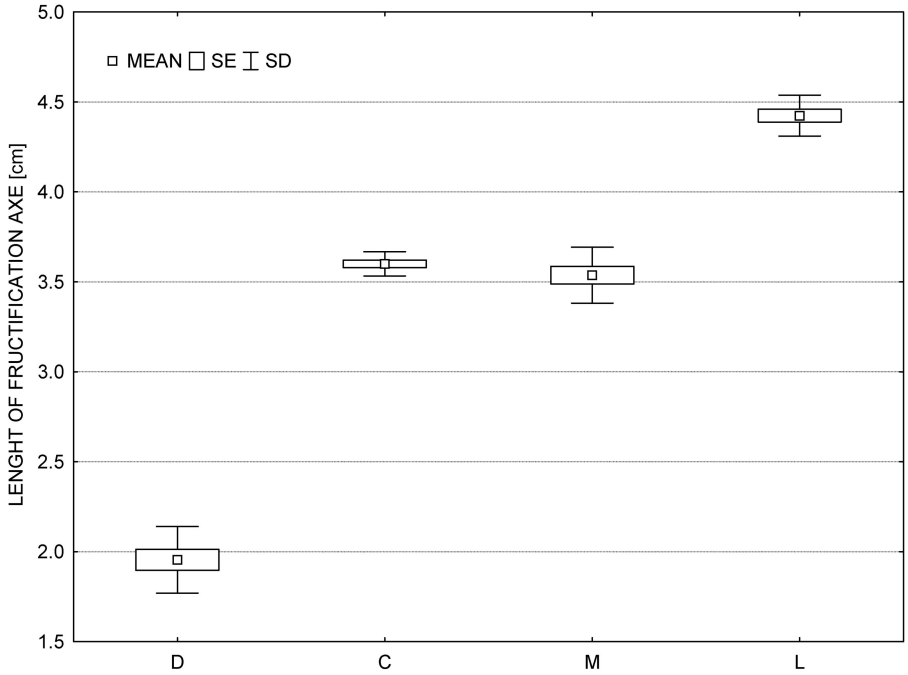


Fig. 37. Descriptive statistics of *B. pendula* length of fructification axes for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

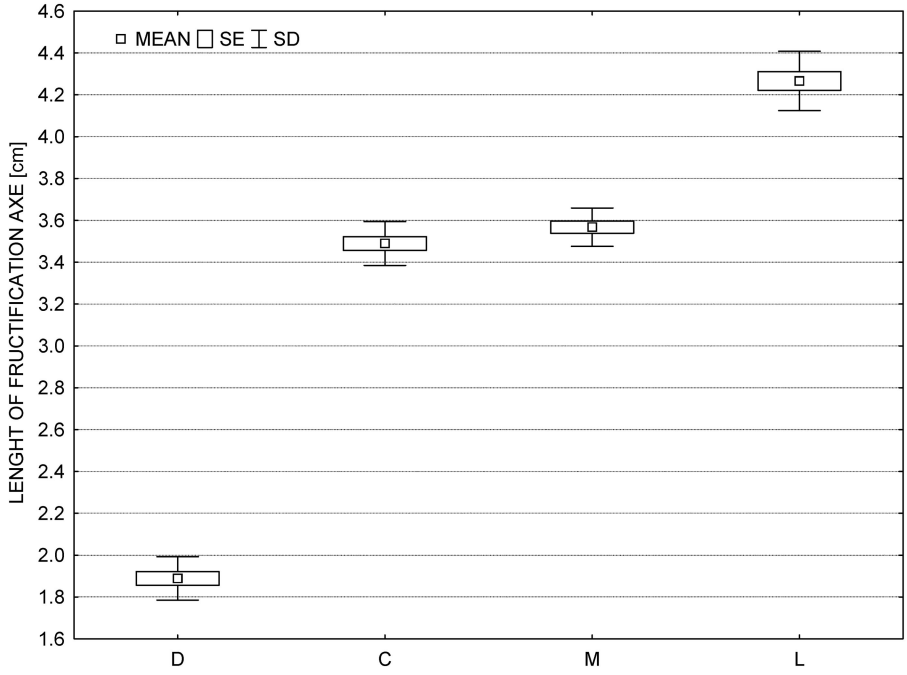


Fig. 38. Descriptive statistics of *B. pendula* length of fructification axes for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

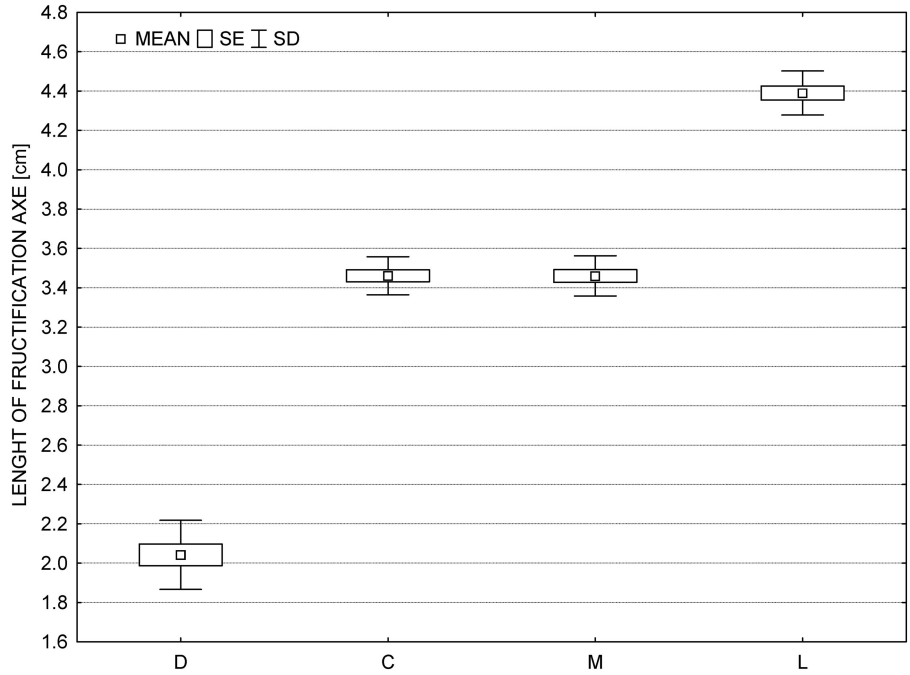


Fig. 39. Descriptive statistics of *B. pendula* length of fructification axes for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The number of nuts per fructification

For three years of this research, the smallest number of nuts — 223 — was recorded for fructifications of birch trees from the zinc-lead dump, whereas the highest one — 504 — for fructifications from Łodygowice. Only in 2006, the largest number of nuts — 273 — was recorded for fructifications of birch trees from Mirów. The above tendency continued for all the growing seasons.

In 2006, the smallest number of nuts — 233 — was recorded for fructifications of birch trees growing on the zinc-lead dump, whereas the largest one — 473 — for fructifications of trees from Mirów (Table 12A). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and the mine waste dump. For other research sites, the differences were insignificant (Fig. 40).

In the subsequent research season of 2007, the smallest number — 288 nuts — was recorded for fructifications of trees from the zinc-lead dump, whereas the largest one of 504 — for fructifications of birch trees from Łodygowice (Table 12B). The T test revealed the statistical significance of differences for all research sites (Fig. 41).

In the subsequent growing season of 2008, fructifications of trees growing on the zinc-lead dump had the smallest number of nuts —258, whereas the largest one — 497 — fructifications of birch trees from Łodygowice (Table 12C). The T test revealed statistically significant differences for all research sites (Fig. 42).

Table 12. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* number of nuts for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 43.62$; $p < 0.01$			
	D	C	M	L
D		0.003*	0.001*	0.001*
C	0.003*		0.001*	0.001*
M	0.001*	0.001*		0.159
L	0.001*	0.001*	0.159	

B

Site	ANOVA/MANOVA $F_{3,36} = 252.43$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 379.16$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

* Significant differences ($p < 0.05$).

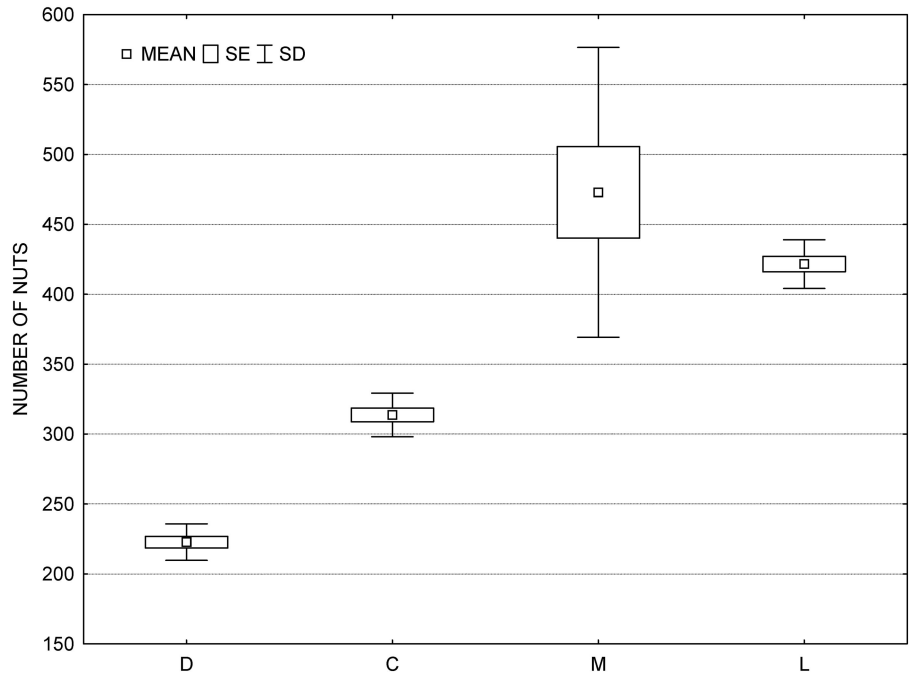


Fig. 40. Descriptive statistics of *B. pendula* number of nuts for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

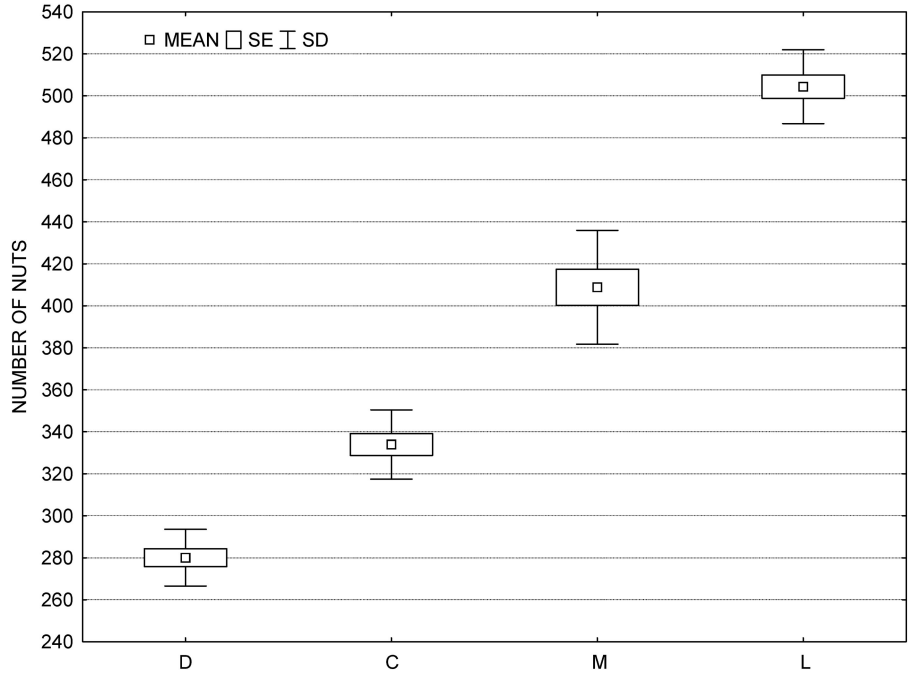


Fig. 41. Descriptive statistics of *B. pendula* number of nuts for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

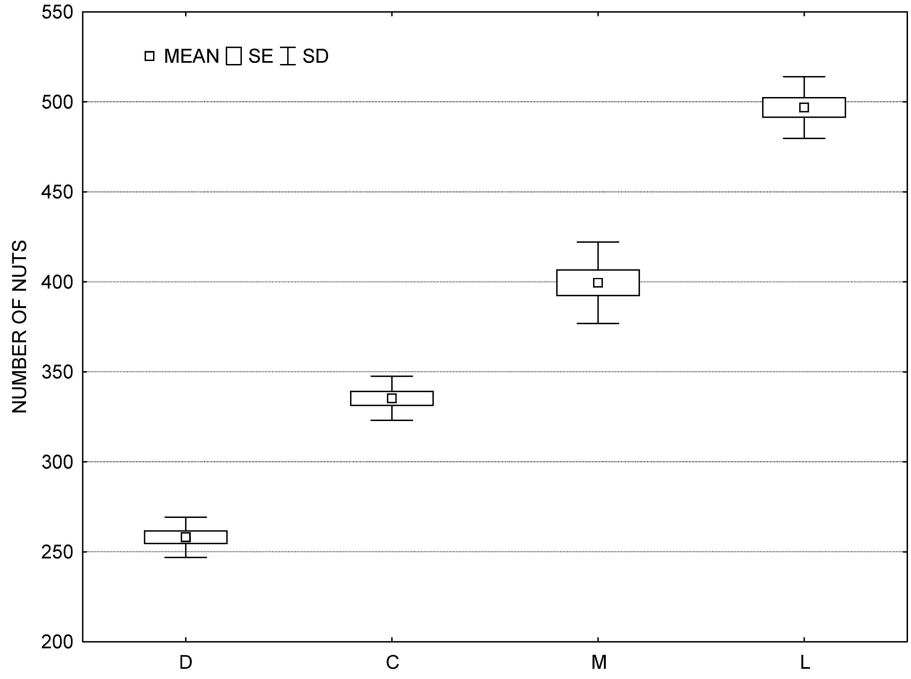


Fig. 42. Descriptive statistics of *B. pendula* number of nuts for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The number of empty nuts per fructification

During the three growing seasons, the largest number — 203 — of empty nuts in fructifications was recorded for birch trees growing on the zinc-lead dump, whereas their smallest number of 64 was recorded for fructifications of trees from the mine waste dump. This tendency continued during all the research years.

In 2006, the smallest number of empty nuts — 64 — was recorded for fructifications of birch trees growing on the mine waste dump, whereas their largest number of 168 was recorded for fructifications of trees from the zinc-lead dump (Table 13A). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and the mine waste dump. For the other sites, no statistically significant differences were recorded (Fig. 43).

In the subsequent research season of 2007, the smallest number of empty nuts — 69 — was recorded for fructifications of birch trees growing on the mine waste dump, whereas the highest one — 203 — for fructifications of trees growing on the zinc-lead dump (Table 13B). The T test revealed significant differences only for the research sites located on the zinc-lead dump and in Łodygowice (Fig. 44).

In 2008, the smallest number of empty nuts — 78 — was recorded for fructifications of birch trees growing on the mine waste dump, whereas their largest number of 194 was recorded for fructifications of trees from the zinc-lead dump (Table 13C). The T test revealed statistically significant differences only for the research sites located on the zinc-lead dump and in Łodygowice (Fig. 45).

Table 13. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* empty seeds for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 80.49$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.010*	0.002*
M	0.001*	0.010*		0.402
L	0.001*	0.002*	0.402	

B

Site	ANOVA/MANOVA $F_{3,36} = 454.64$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.540	0.001*
M	0.001*	0.540		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F^{3,36} = 375.11$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.967	0.002*
M	0.001*	0.967		0.004*
L	0.001*	0.002*	0.004*	

* Significant differences ($p < 0.05$).

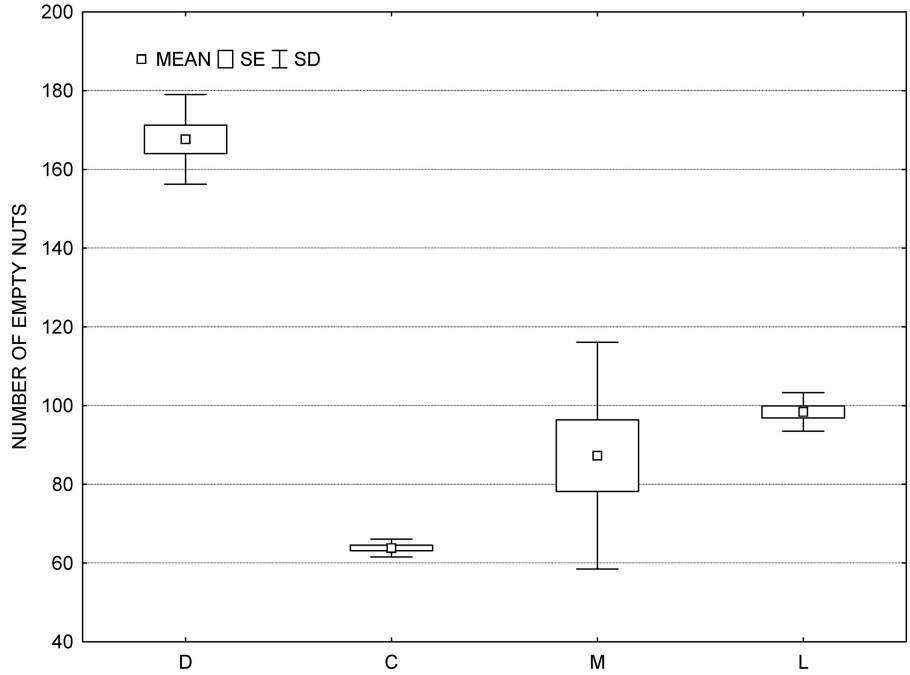


Fig. 43. Descriptive statistics of *B. pendula* number of empty nuts for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

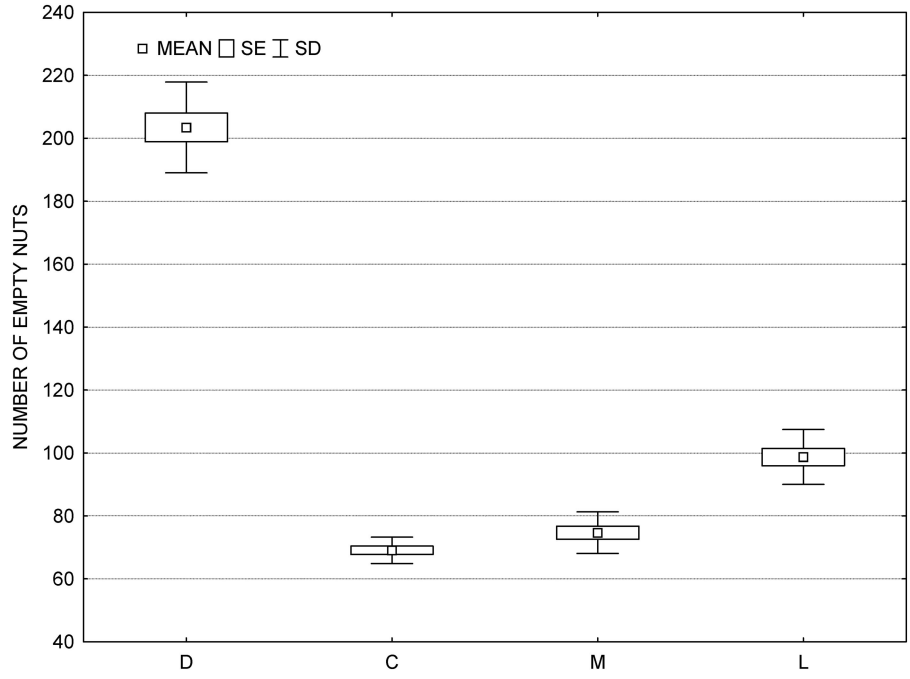


Fig. 44. Descriptive statistics of *B. pendula* number of empty nuts for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

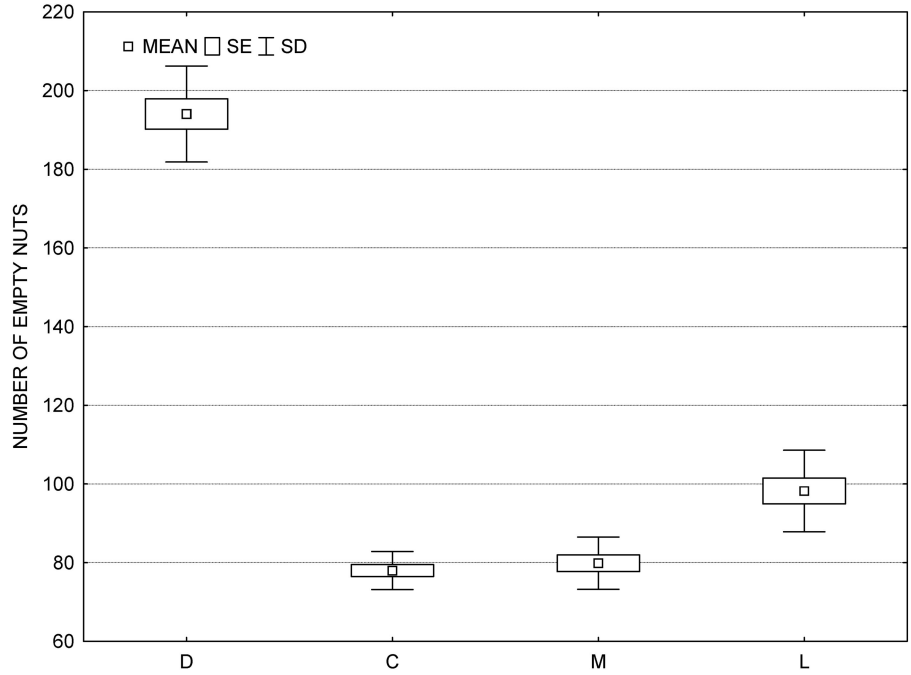


Fig. 45. Descriptive statistics of *B. pendula* number of empty nuts for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

The number of full nuts per fructification

During the three growing seasons, the smallest number — 55 — of full nuts was recorded for fructifications of birch trees from the zinc-lead dump, whereas the highest one — 406 — for fructifications of trees from Łodygowice. Only in 2006, the highest number — 385 — of full nuts was recorded for fructifications of birch trees from Mirów. This tendency continued for all the years of this research.

In 2006, fructifications of birch trees from the zinc-lead dump had the smallest number of full nuts — 55, whereas the largest number — 385 — was recorded for fructifications of trees from Mirów (Table 14A). The T test revealed statistical significance of differences for all research sites (Fig. 46).

In the subsequent research season of 2007, the smallest number of full nuts — 57 — was recorded for fructifications of birch trees from the zinc-lead dump, whereas their largest number — 406 — for fructifications of trees growing in Łodygowice (Table 14B). The T test revealed statistically significant differences for all research sites (Fig. 47).

In the subsequent research season of 2008, the smallest number — 64 — of full nuts was recorded for fructifications of birch trees from the zinc-lead dump, whereas the highest one — 398 — for fructifications of trees growing in Łodygowice (Table 14C). The T test revealed statistically significant differences for all research sites (Fig. 48).

Table 14. One-way ANOVA and Tuckey's honesty significant difference test of *B. pendula* full seeds for three years (A — 2006, B — 2007, C — 2008); Site abbreviation see fig. 4

A

Site	ANOVA/MANOVA $F_{3,36} = 126.1$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.007*
L	0.001*	0.001*	0.007*	

B

Site	ANOVA/MANOVA $F_{3,36} = 656.36$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

C

Site	ANOVA/MANOVA $F_{3,36} = 497.54$; $p < 0.01$			
	D	C	M	L
D		0.001*	0.001*	0.001*
C	0.001*		0.001*	0.001*
M	0.001*	0.001*		0.001*
L	0.001*	0.001*	0.001*	

* Significant differences ($p < 0.05$).

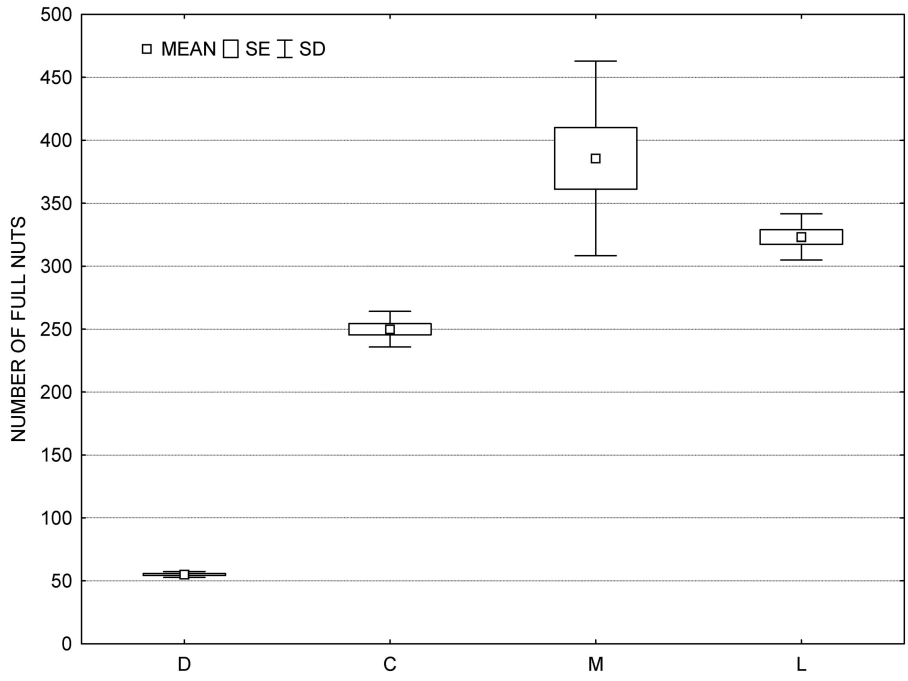


Fig. 46. Descriptive statistics of *B. pendula* number of full nuts for 2006; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

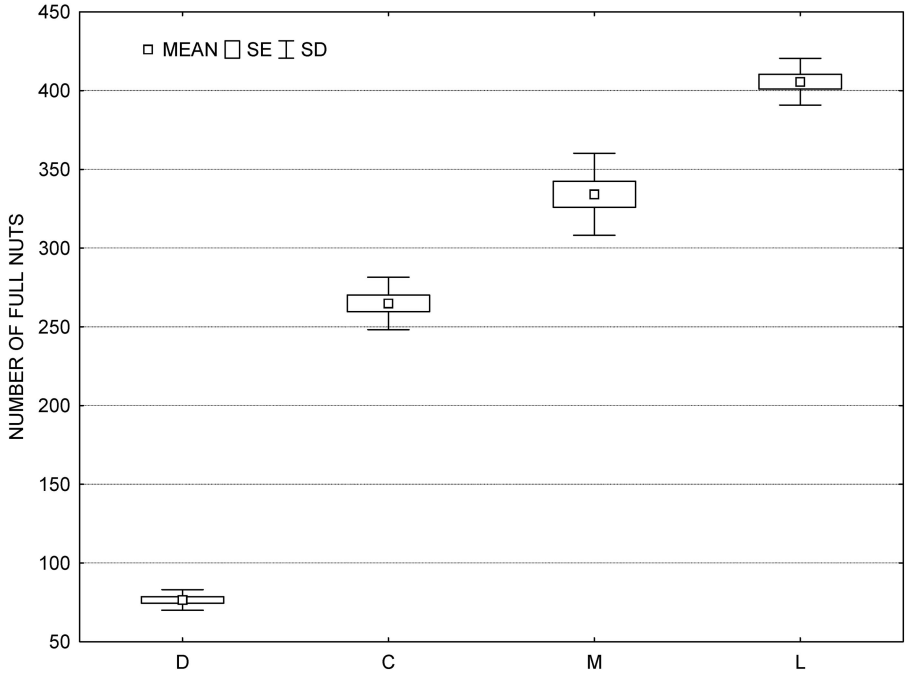


Fig. 47. Descriptive statistics of *B. pendula* number of full nuts for 2007; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

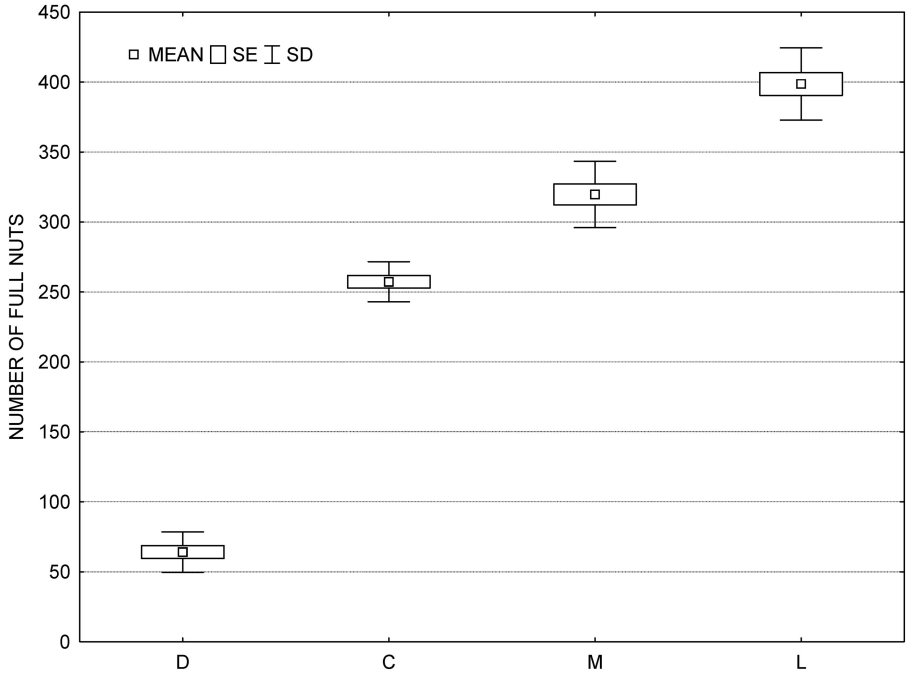


Fig. 48. Descriptive statistics of *B. pendula* number of full nuts for 2008; mean, standard deviation, standard error. Site abbreviation: D, C, M, L see fig. 4

Efficiency of pollen germination

Germination power is a biological parameter describing the pollen viability, and it describes the percentage contribution of pollen grains germinating on the culture medium of agar and saccharose. When analysing the results obtained, one can state that the lowest value of germination power was obtained for pollen of birch trees from the zinc-lead dump (3.34% in 2006, 10.45% in 2007 and 1.98% in 2008), whereas the highest value of this parameter was recorded for pollen of trees growing in Łodygowice (97.40% in 2006, 98.20% in 2007, 96.17% in 2008). The value of germination power of pollen from trees in Mirów was reduced by only 3%, as compared to pollen of birch trees from Łodygowice, and for growing seasons 2006—2008 it reached: 94.88%, 95.16%, 93.79% respectively. For pollen of birch trees growing on the mine waste dump, the value of the studied parameter was reduced by 20% as compared to the results obtained for the pollen of trees from Łodygowice, and amounted to: 71.17% for 2006, 69.35% in 2007 and 69.64% in 2008 (Fig. 49).

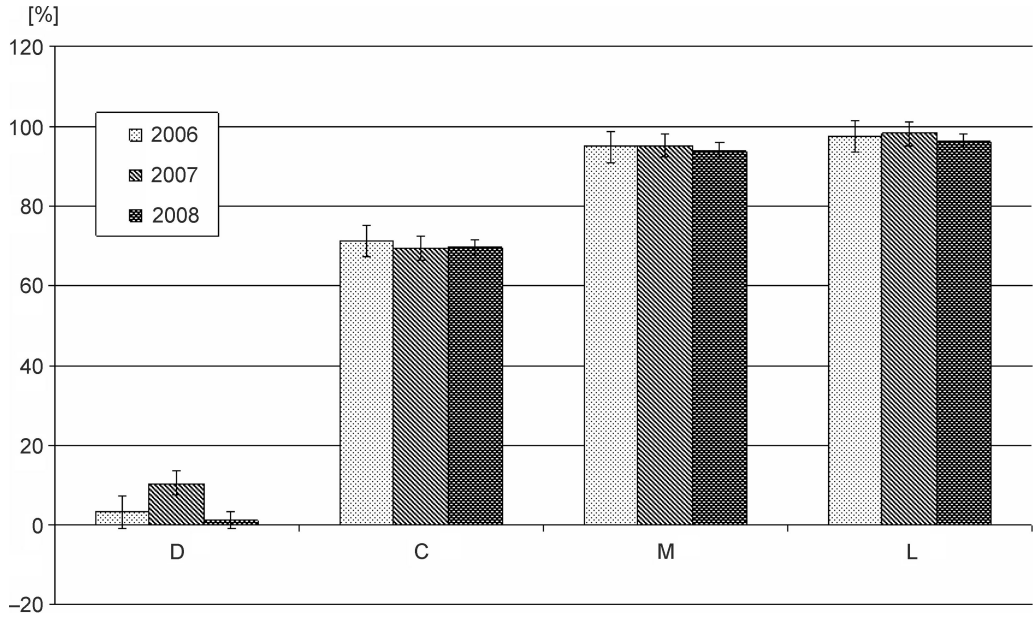


Fig. 49. Pollen germination percentage of *B. pendula* for three consesutive growing seasons and each study area (mean and standard deviation)

Germination of birch seeds

Parameters describing the sowing value of seeds are the ability and energy of germination. The former term means the percentage contribution of seeds ready for germination in the conditions suitable for a species. The latter one applies to the number of germination days for each seed of a given sample and is expressed by the Pieper coefficient.

Germination capacity

When analysing the results obtained, one can observe that the lowest value of germination capacity of seeds was obtained for trees from the zinc-lead dump (20% in 2006, 21.60% in 2007, 10.40% in 2008), whereas the highest value of this parameter was obtained for seeds: from Mirów 48.60% in 2006, Mirów and Łodygowice 40.80% and 40% in 2007 and Łodygowice 47.80% in 2008 (Fig. 50). One should emphasize that the value of this parameter was two or even four times higher for birch seeds from Mirów and Łodygowice as compared to seeds from the zinc-lead dump. During the three research seasons, the germination capacity of seeds of birch trees growing on the mine waste dump was higher by ca. 5—20% as compared to the value of this parameter obtained for birch seeds from the zinc-lead dump.

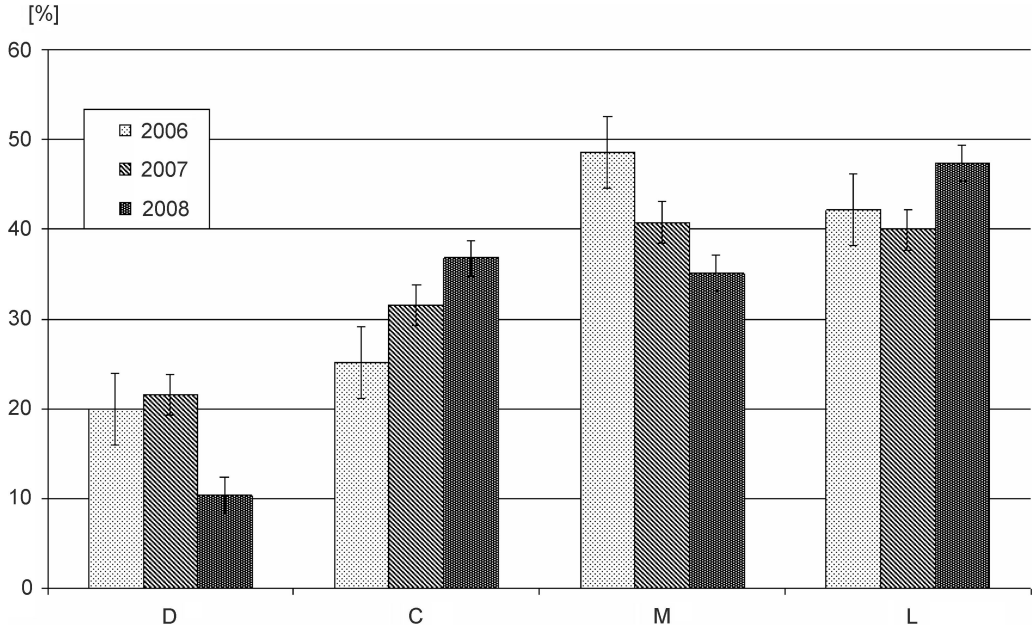


Fig. 50. Seed germination power of *B. pendula* for three consesutive growing seasons and each study area (mean and standard deviation)

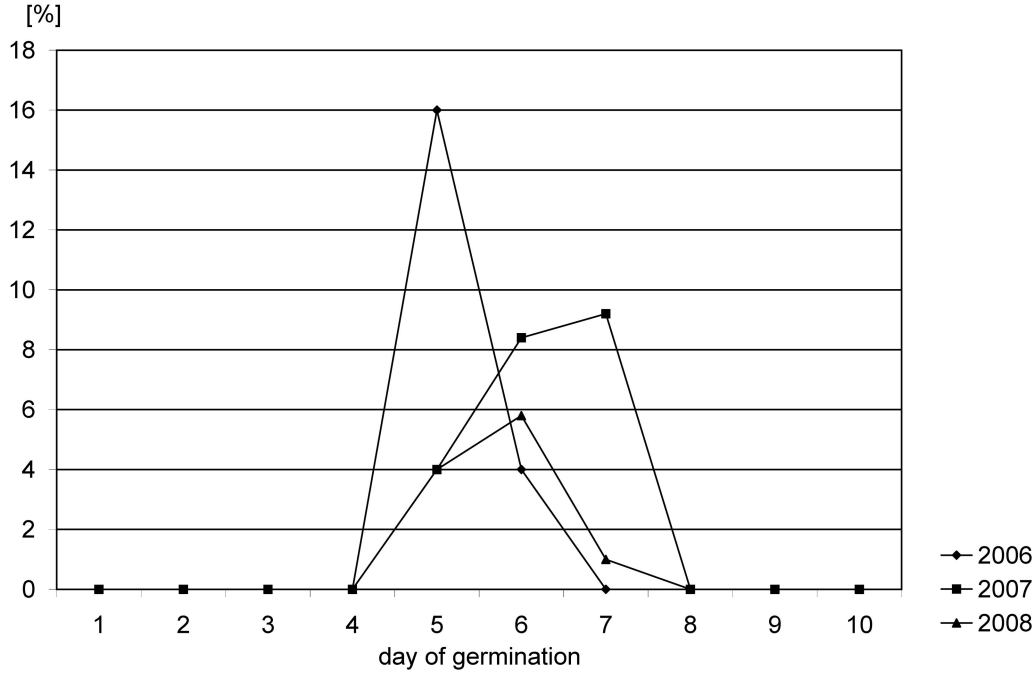


Fig. 51. Seed germination dynamics of *B. pendula* populations from zinc-lead dump

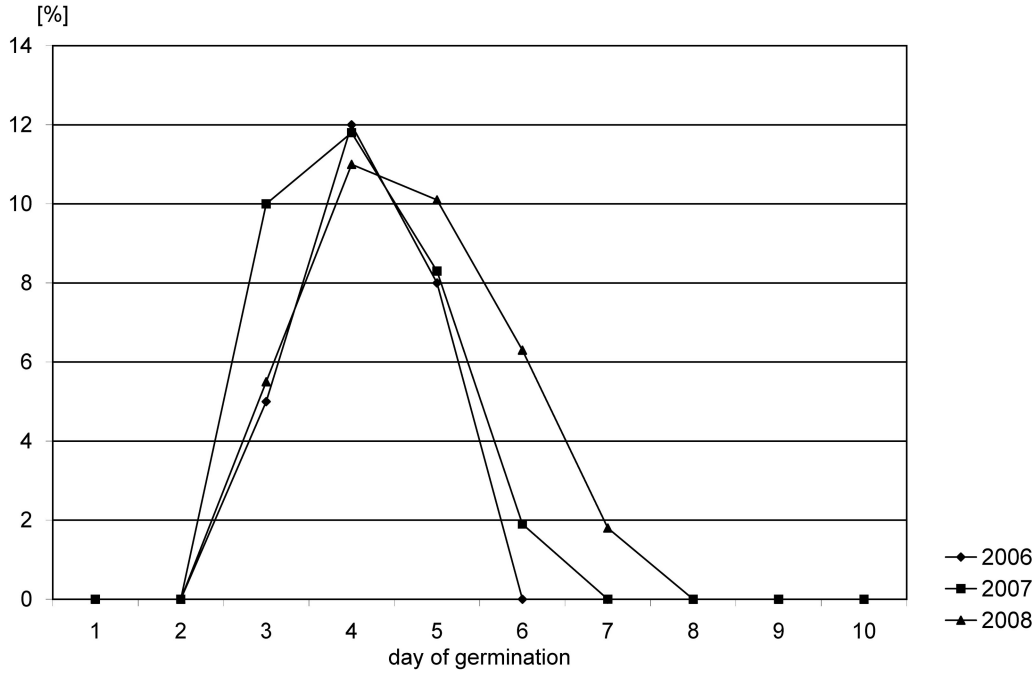


Fig. 52. Seed germination dynamics of *B. pendula* populations from coal-mine waste dump

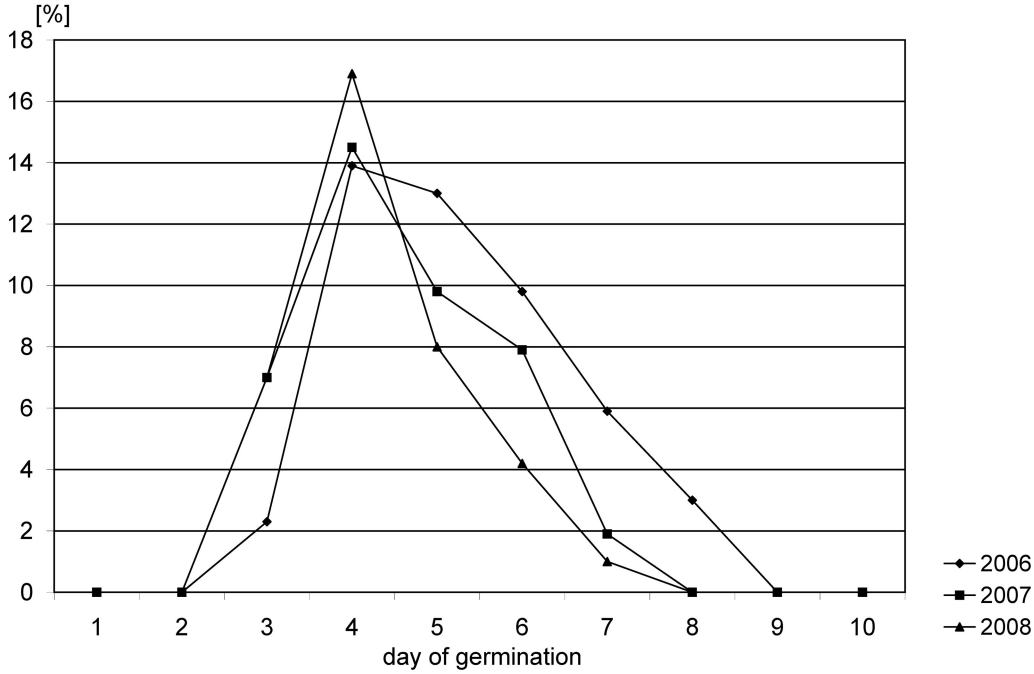


Fig. 53. Seed germination dynamics of *B. pendula* populations from Mirów research area

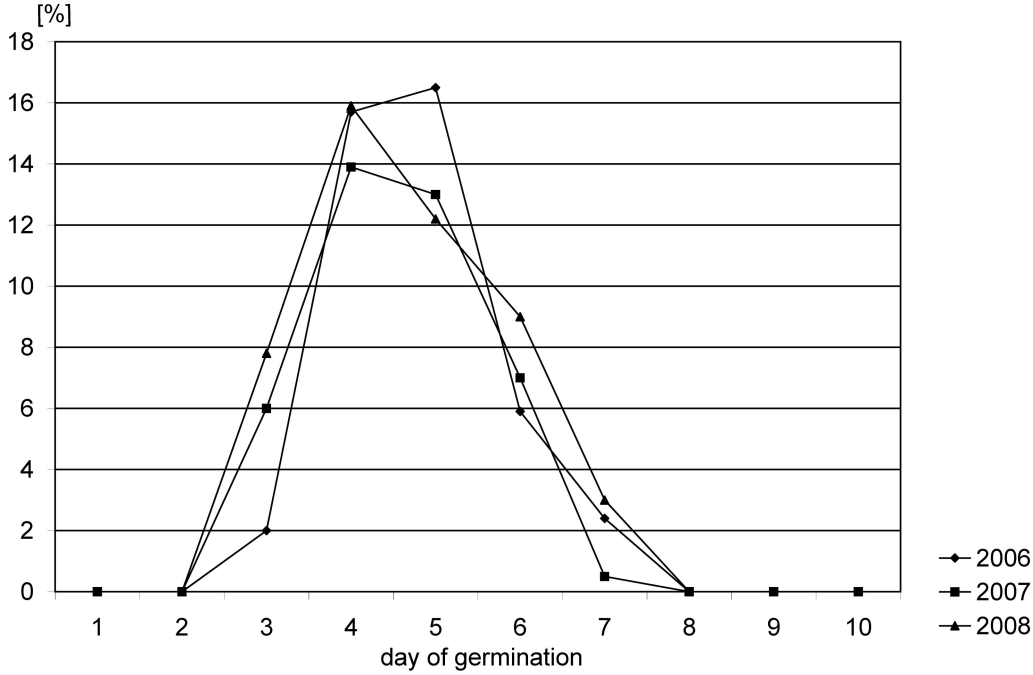


Fig. 54. Seed germination dynamics of *B. pendula* populations from Łodygowice research area

Figures 51—54 presents the dynamics of germination of birch seeds for all research sites in the years 2006—2008. Diagrams of the germination dynamics illustrate the ability of seeds to germinate during the next day of the performed test. It is noteworthy that during all the growing seasons for three research sites — the mine waste dump, Mirów and Łodygowice, the peak of germination of seeds occurred on the fourth day, whereas for seeds of trees from the zinc-lead dump, the germination peak occurred on the fifth day, and in 2007 — on the seventh day of the performed test.

Germination energy expressed by the Pieper coefficient

For all the research years this coefficient for seeds from all the research sites fluctuated between 0.81 and 1.24 days. One should emphasized that this coefficient has values above 1 only for seeds coming from the zinc-lead dump (Fig. 55).

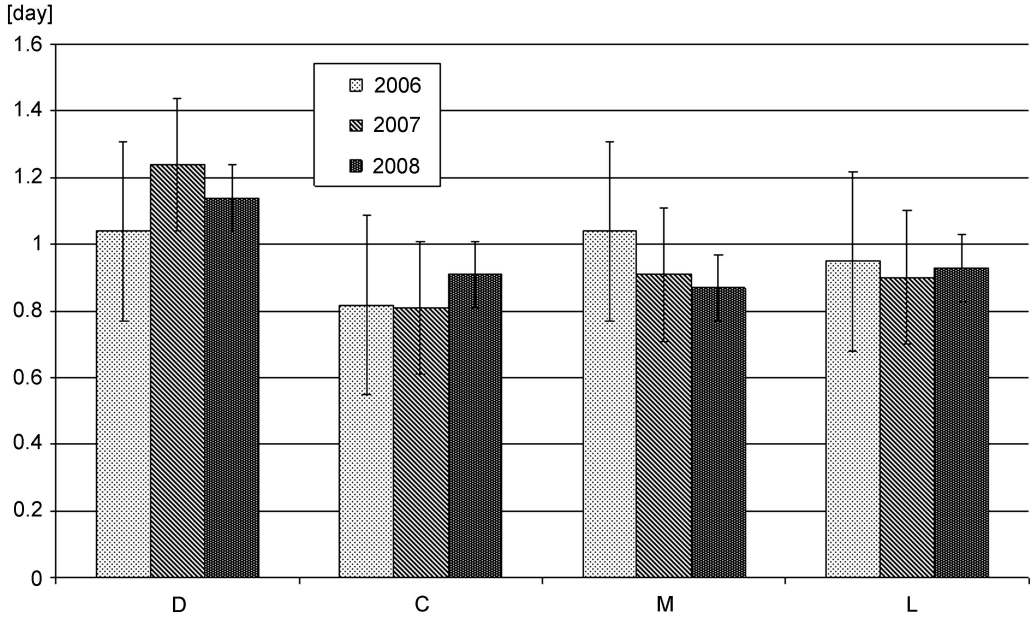


Fig. 55. Pieper coefficent of *B. pendula* for three consecutive growing seasons and each study area (mean and standard deviation)

Correlation analysis of the obtained results

The results obtained in this study were analysed with the correlation analysis in order to investigate the relationships between:

— the content of photosynthetic pigments and the surface area of leaves,
— the number, as well as the surface area of leaves and the number of pistillate and staminate inflorescences,
— the number of nuts and the number of leaves, the number of pistillate inflorescences and the length of fructifications,
— the number of full nuts and the length of fructification axe.

Table 15 includes only pairs of parameters statistically significantly correlated with each other, as well as values of the correlation coefficient.

Table 15. Correlation significant coefficient between parameters of *B. pendula* traits from all research sites and all years

Parameters	Site	r (x, y)	N	p
Chlorophyll a : lamina surface area	D	–0.871	30	0.01
Chlorophyll b : lamina surface area	D	–0.883	30	0.01
Carotenoids : lamina surface area	D	–0.887	30	0.01
Chlorophyll a : lamina surface area	C	–0.374	30	0.01
Chlorophyll b : lamina surface area	C	–0.466	30	0.01
Carotenoids : lamina surface area	C	–0.367	30	0.01
Number of leaves : number of staminate inflorescent	L	–0.377	30	0.01
Number of leaves : number of pistillate inflorescent	L	–0.401	30	0.01
Number of leaves : number of nuts	M	0.408	30	0.01
Lamina surface area : number of staminate inflorescent	M	–0.407	30	0.01
Lamina surface : number of pistillate inflorescent	M	–0.586	30	0.01
Number of nuts : number of pistillate inflorescent	M	–0.412	30	0.01
Number of nuts : length of fructification axes	C	–0.381	30	0.01
Number of full nuts : length of pistillate inflorescent	M	0.339	30	0.01
Number of full nuts : length of pistillate inflorescent	L	–0.662	30	0.01

Within the correlation of the group of parameters describing the photosynthetic apparatus of birch, noteworthy are the negative correlation coefficients between the content of photosynthetic pigments and the lamina surface area for birch specimens coming from the slag and mine waste heaps. Among the correlation coefficients between parameters describing the biometric characteristics of generative organs, the following aspects seem interesting:

— the negative correlation coefficient between the number of nuts in a fructification and the number of pistillate inflorescences for birch specimens coming from Mirów,
— the negative correlation coefficient between the number of nuts in a fructification and the length of fructifications' axes for trees growing on the mine waste dump,
— the negative correlation coefficient between the number of full nuts in a fructification and the length of pistillate inflorescences for birch specimens selected in Łodygowice, as well as the positive correlation coefficient for the same parameters for trees growing in Mirów.

Furthermore, negative correlation coefficients between the following parameters are noteworthy: the number of leaves and the number of staminate and pistillate inflorescences for trees growing in Łodygowice, the positive correlation coefficient between the parameters — the number of leaves and the number of nuts in a fructification for birch specimens from Mirów, as well as negative correlation coefficients between the surface area of leaves and the number of staminate and pistillate inflorescences calculated for the same trees.

The correlation analysis revealed no statistically significant correlations between:
— the surface area of leaves and their number,
— the length of pistillate inflorescences and the length of fructifications' axes,
— the length of fructifications' axes and the number of full nuts in a fructification.

Geostatistical analysis

Geostatistical analysis provided detailed information on the spatial structure of the studied variables.

Visualization of variables

Visualization of the density of seedlings and selected habitat factors (soil moisture and solar radiation intensity) was completed with the program R-CRAN. The mapped data for particular sites are presented in Figures 56—58.

High values of the studied variables are marked with gray colour, low values — with black colour. In most cases, mapping of data indicates high heterogeneity of the studied variables. Visualization is used in further analysis of the spatial structure by means of variograms.

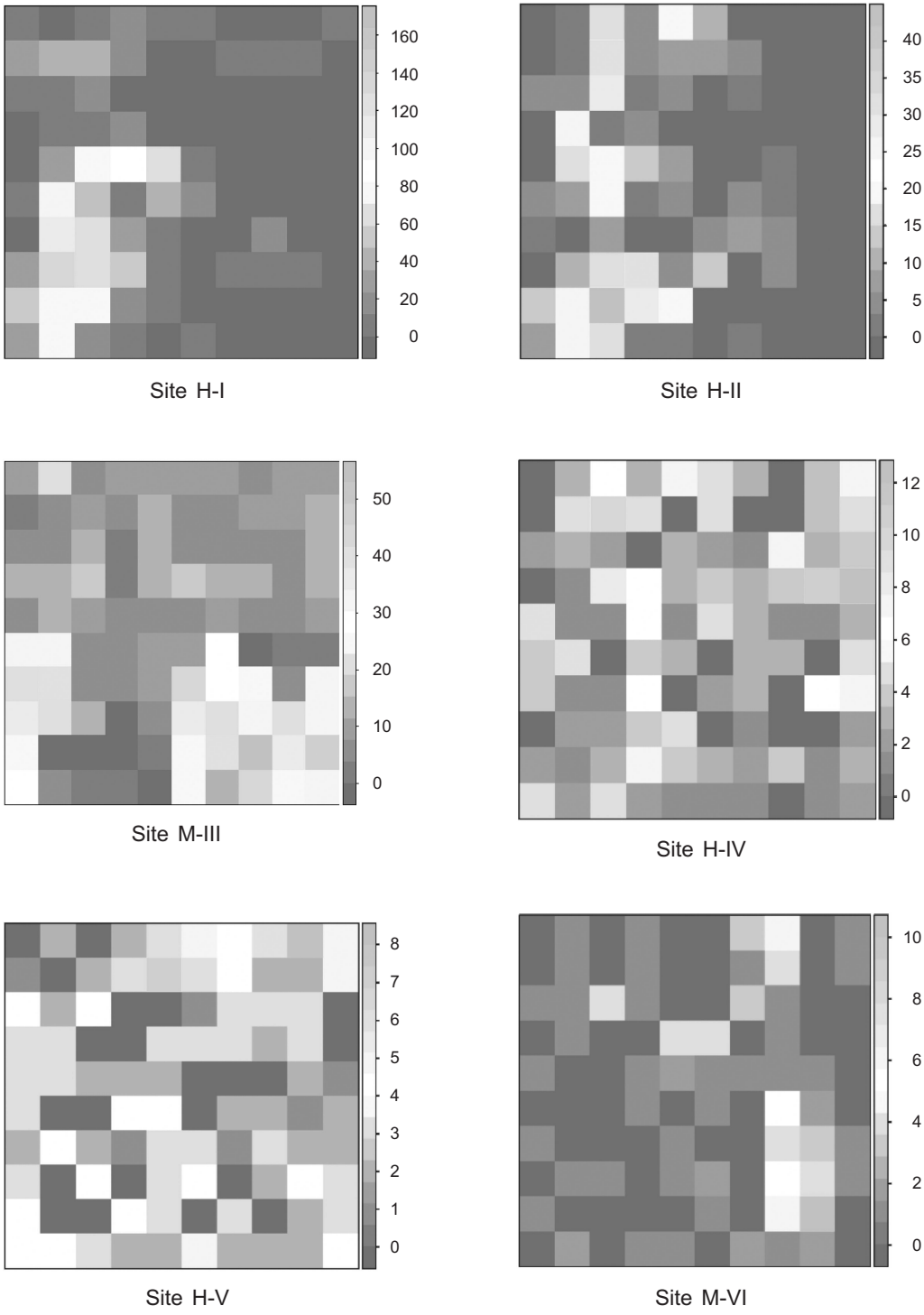
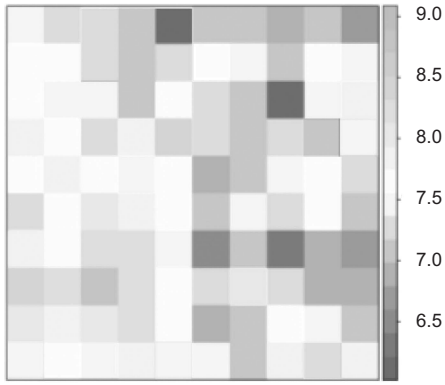
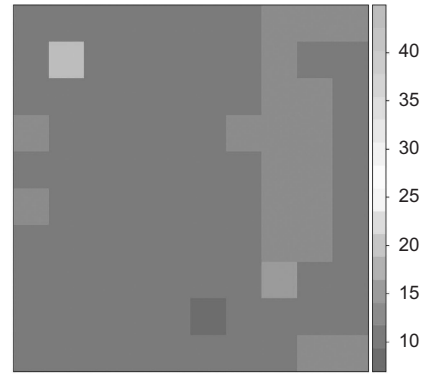


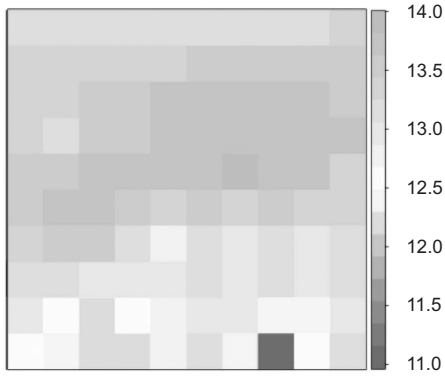
Fig. 56. Spatial pattern of the density of *B. pendula* seedlings



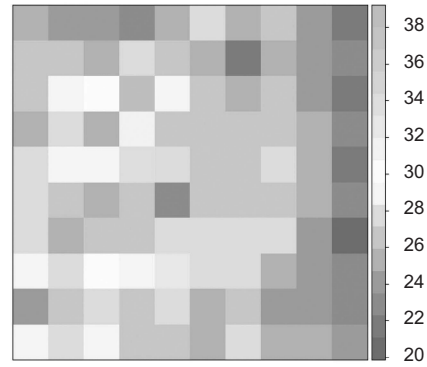
Site H-I — June



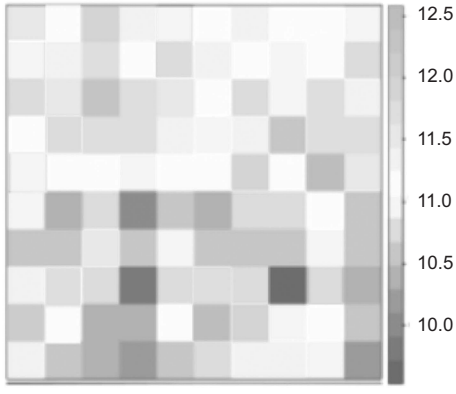
Site H-I — September



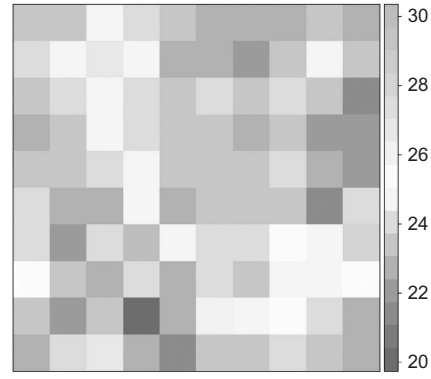
Site M-VI — June



Site M-VI — September



Site H-IV — June



Site H-IV — September

Fig. 57. Spatial pattern of the soil moisture

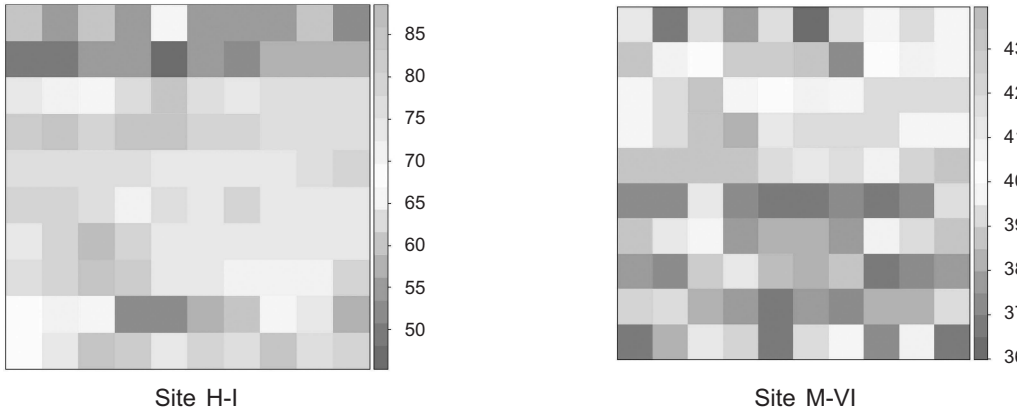


Fig. 58. Spatial pattern of the solar radiation intensity

Preliminary analysis of the collected data

Spatial variability of the soil moisture, density of *B. pendula* seedlings and light intensity (PPFD) were analysed with classical statistics (average values, standard deviation, asymmetry and kurtosis), and their results were compiled in Table 16—18.

Table 16. Statistics of *B. pendula* seedlings density per basic plot from zinc-lead dump and Mirów area (*SD* — standard deviation, *CV* — coefficient of variation)

Site	Seedlings max	Seedlings min	*SD*	*CV*	Kurtosis	Asymmetry
H-I	162	0	31.00	1.86	6.60	2.50
H-II	47	0	9.00	1.50	2.90	1.80
M-III	54	1	12.30	0.89	0.60	1.20
H-IV	19	0	2.90	0.91	1.20	1.20
H-V	9	0	1.70	0.73	0.50	0.40
M-VI	11	1	1.70	1.53	8.10	2.50

Table 17. Statistics of soil moisture (June and September) from zinc-lead dump and Mirów areas (*SD* — standard deviation, *CV* — coefficient of variation)

Site	Mean	*SD*	*CV*	Kurtosis	Asymmetry
moisture in June					
H-I	7.55	0.51	0.06	0.09	–0.06
M-VI	14.89	0.45	0.03	3.78	–1.48
H-IV	11.1	0.59	0.06	1.1	–0.12
moisture in September					
H-I	11.22	3.31	0.29	83.97	8.81
M-VI	26.28	2.61	0.09	3.97	1.04
H-IV	23.69	1.32	0.05	4.50	1.28

Table 18. Statistics of PPFD (solar radiation intensity) from zinc-lead dump and Mirów area (*SD* — standard deviation, *CV* — coefficient of variation)

Site	Mean	*SD*	*CV*	Kurtosis	Asymmetry
H-I	70.44	10.07	0.14	–0.64	–0.70
M-VI	39.25	1.77	0.04	–0.63	0.39

It appears from the analyses performed that seedlings of *B. pendula* at particular research sites were characterized by very diverse count and average density. Taking into account the sites located within the dumping grounds (sites H-I, H-II, H-IV, H-V), the average number of seedlings per one square metre fluctuated between as many as 16.7 at site H-I (the highest recorded value) and 2.3 at site H-V. In the remaining cases, values did not exceed 6 specimens per plot.

Standard deviation and the coefficient of variation were the measures of dispersion in the values of density. The highest variation in the density of seedlings was observed within the site H-I (where the highest density was recorded) and at sites H-II and M-VI (values of the coefficient of variation were 1.86, 1.50 and 1.53, respectively). At the remaining sites, values of the coefficient of variation were much smaller. At site M-III, despite high individual density, the value of the coefficient of variation was much lower than at site M-VI.

Statistics characterizing the frequency distribution of seedlings — histograms (asymmetry and kurtosis) — in all the cases indicate strong right-side asymmetry and high concentration of count values around the average value.

The analysis of the soil moisture content revealed that its average values at site H-IV in the older part of the heap and in Mirów are similar, and at the same time more than twice as high as the average values recorded at site H-I.

When analysing the volumetric water content (Table 17), one can notice that average values are much higher in September. At the research site H-I located within the heap the differences fluctuated at the level of 50%. Particularly high differences were observed at sites M-VI and H-IV, where soil moisture during that period was almost 100% higher as compared to June. Taking into account the standard deviation, it was found that at both aforementioned sites the dispersion of the moisture content in June and September was similar (June 0.5, September ca. 3). Values of the coefficient of variation at sites H-I and M-VI were much higher in September, whereas at site H-IV — the value was only slightly higher in June. Asymmetry of the soil moisture distribution in September was right-sided, whereas in June — left-sided.

Measurements of the light intensity revealed that average values of the relative photosynthetic photon flux density (PPFD) were higher on the dump (site H-IV), and lower in the nature site (site M-VI). This difference was significant and amounted to 80%. Higher spatial heterogeneity of the described parameter was recorded within site H-IV.

Values of the standard deviation and also the coefficient of variation were significantly higher at site H-I (10.07 and 0.14), whereas at site M-VI it amounted to 1.77 and 0.04 respectively).

Asymmetries in the light intensity distribution were right-sided at site M-VI, whereas left-sided — at site H-I; in both cases — they had slightly flattened distribution (Table 18).

Calculation of empirical variograms and selection of theoretical variograms

Empirical variograms determined on the basis of direct measurement data together with fitted models are presented in Figures 59—63. Values of nugget, sills and the autocorrelation range for particular variables are presented in Table 19—21. Small values of AIC and RMSE indicate high goodness of fit of theoretical models to empirical data of variograms.

In the case of the density of seedlings, the geostatistical analysis revealed a spatial relationship at four research areas: two of them covered the area of the zinc-lead waste dump (sites H-I, H-II), two others — the area of Mirów (site M-III, M-VI). Values of the spatial autocorrelation range presented in Table 19 (the range value) indicate that at two research sites (H-I and M-III), the size of clumps was similar and amounted to ca. 5 m. A smaller range of clumps, as compared to the above-mentioned, was observed at sites M-VI and H-II (2.2 m and 4.2 m, respectively).

Spatial variability in the density of seedlings is not perfectly continuous — the effect of nugget was recorded at all research sites. The highest variation in the density of seedlings (the highest contribution of nugget in the variogram structure) was recorded at sites H-IV and H-V. Geostatistical analysis revealed the presence of a slight spatial trend at sites H-IV and H-V, which is manifested in a constant increase of the variogram, preventing the determination of a sill value.

Table 19. Parameters of variograms for the variable: density of seedlings

Site	Model	Nugget	Sill	Range	RMSE	AIC
H-I	Spherical	242.80	863.80	5.50	3.44	1.10
H-II	Spherical	42.58	96.01	4.20	1.25	4.23
M-III	Spherical	28.79	137.20	5.40	6.44	73.36
H-IV	Spherical	6.58	2953.80	max	0.56	19.90
H-V	Spherical	2.24	2651	max	0.04	–38.38
M-VI	Spherical	2.14	914.10	2.20	0.14	–10.71

In the case of the variable soil moisture, geostatistical analysis revealed spatial autocorrelation of the soil moisture (soil substrate) at sites M-VI and H-IV — in September and at sites H-I and H-IV — in June. Values of the spatial autocorrelation range presented in Table 20 (the range value) at two research sites M-VI and H-IV were similar and amounted to ca. 2 m. A larger range of spatial autocorrelation — higher range, as compared to the above-mentioned, was observed at sites M-VI and H-IV.

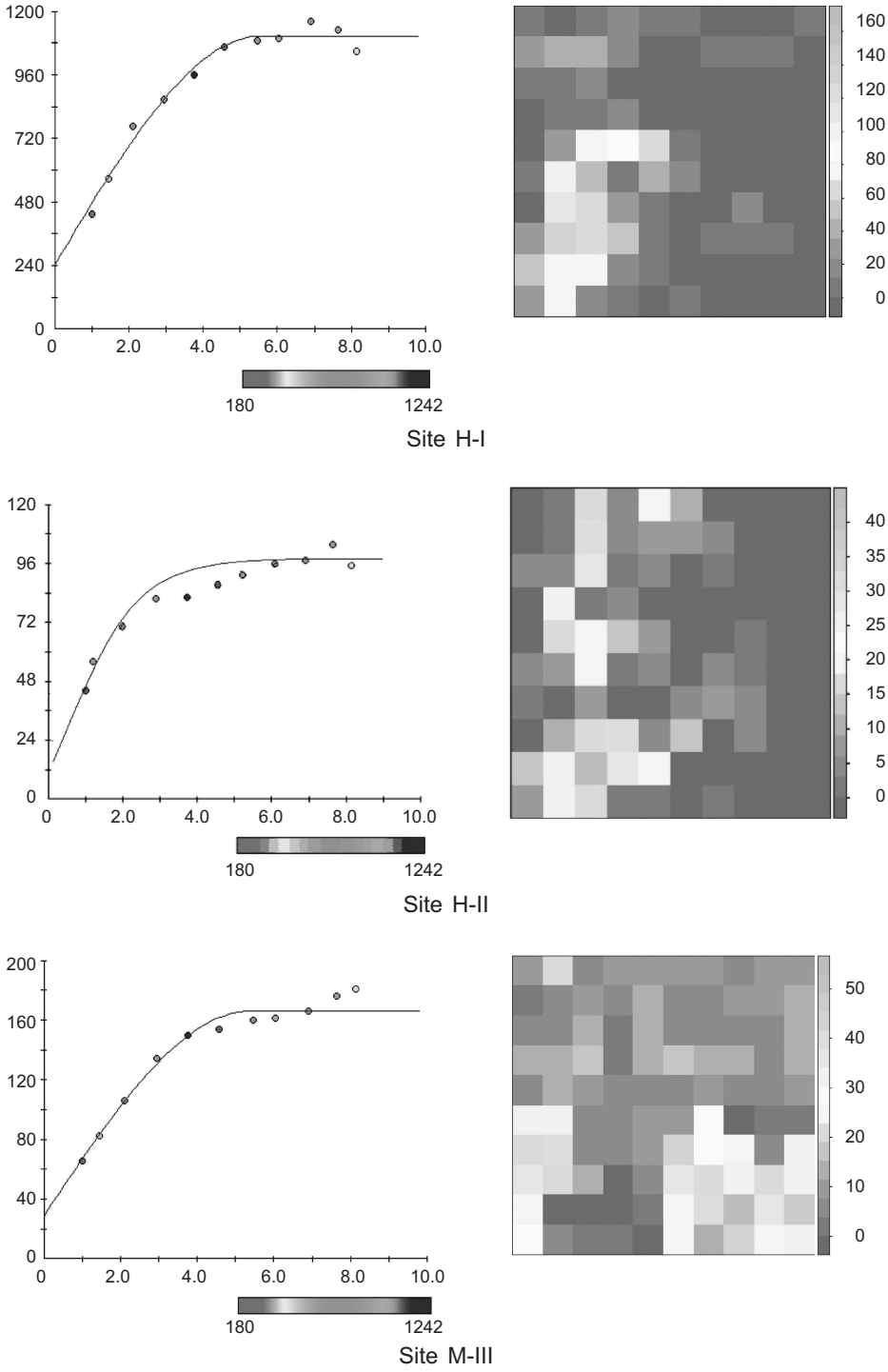


Fig. 59. Empirical variogram of the seedlings' density and the fitted mathematical model together with mapping

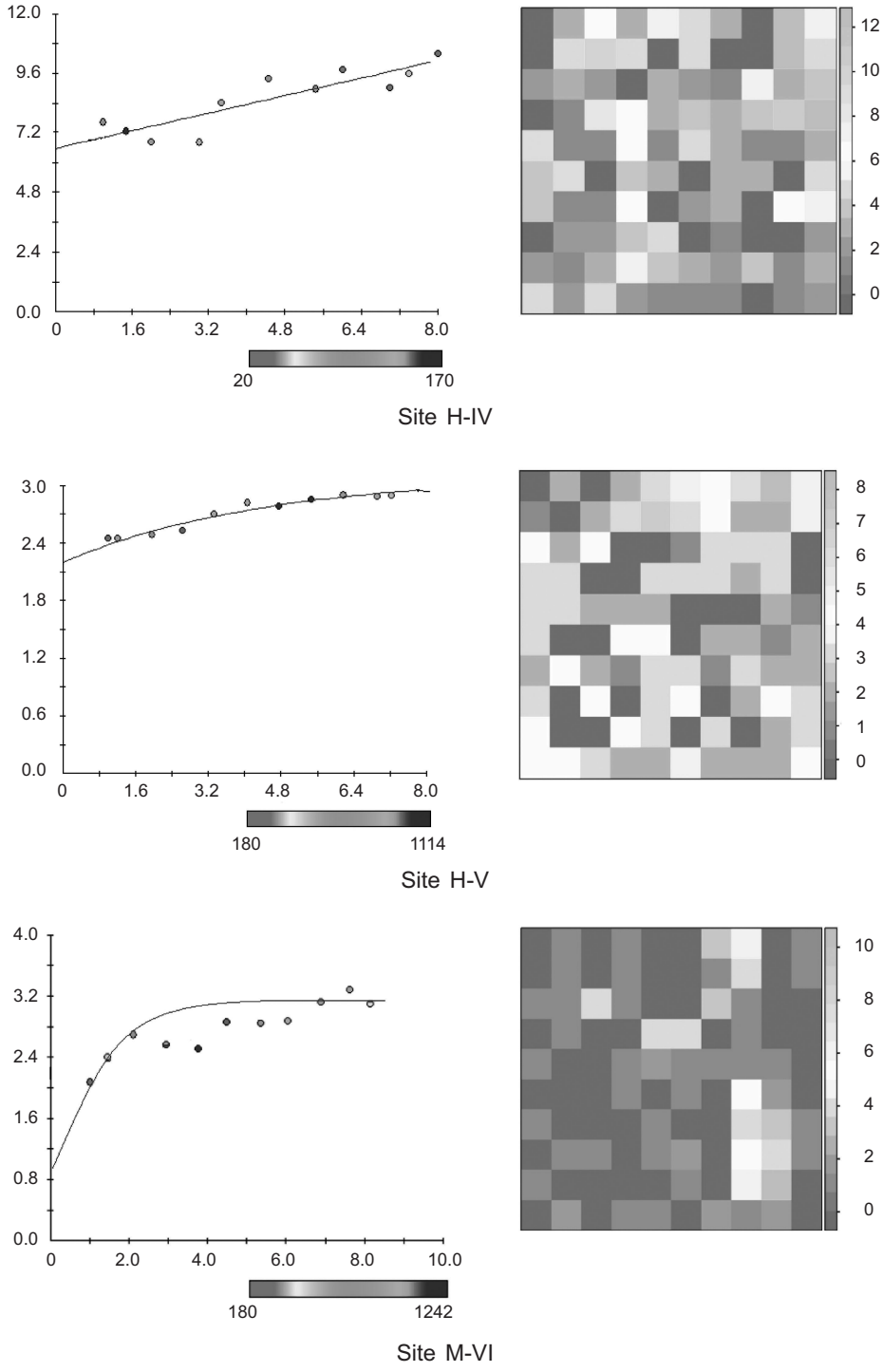


Fig. 60. Empirical variogram of the seedlings' density and the fitted mathematical model together with mapping cont.

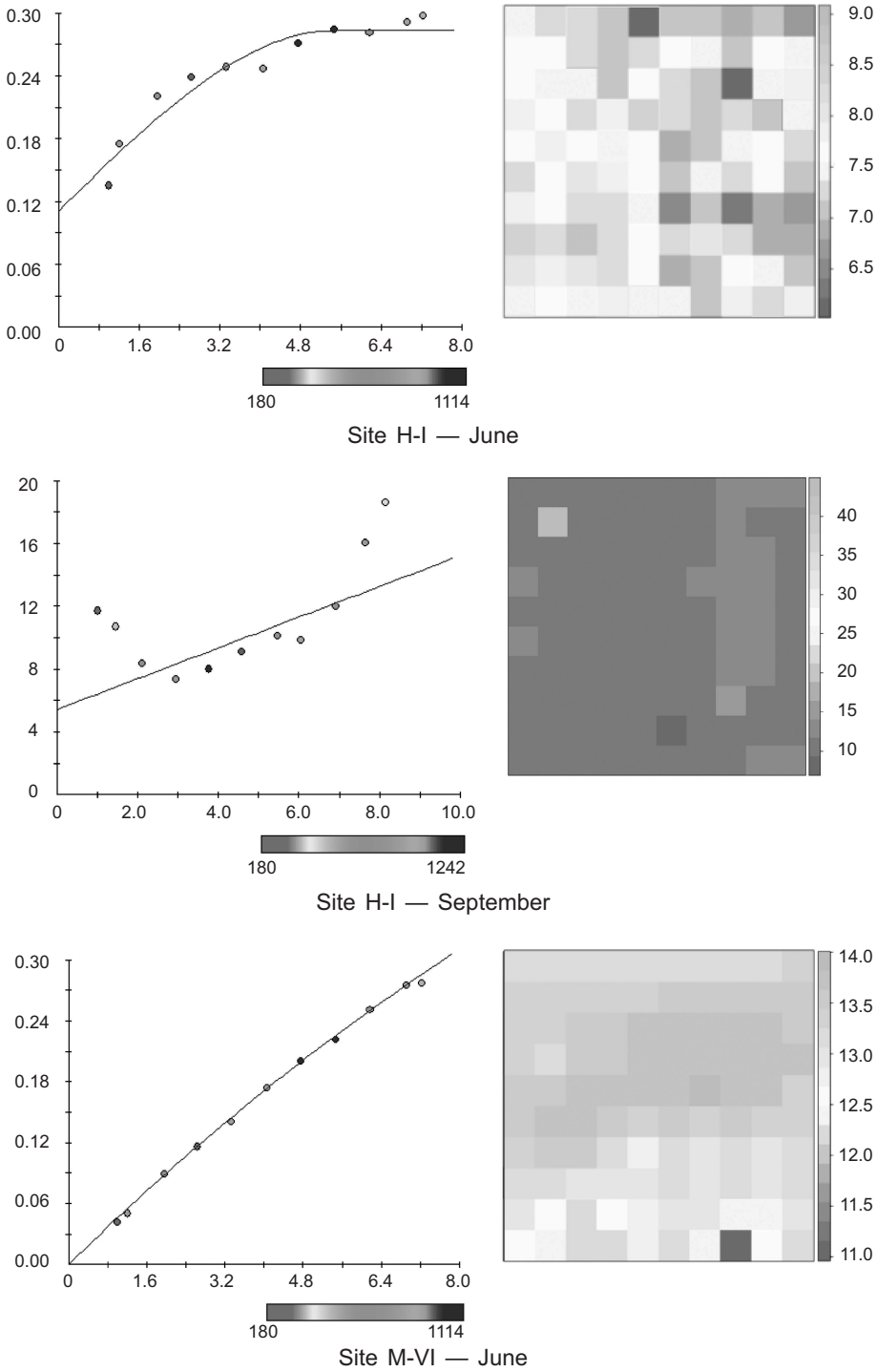


Fig. 61. Empirical variogram of the soil moisture and the fitted mathematical model together with mapping

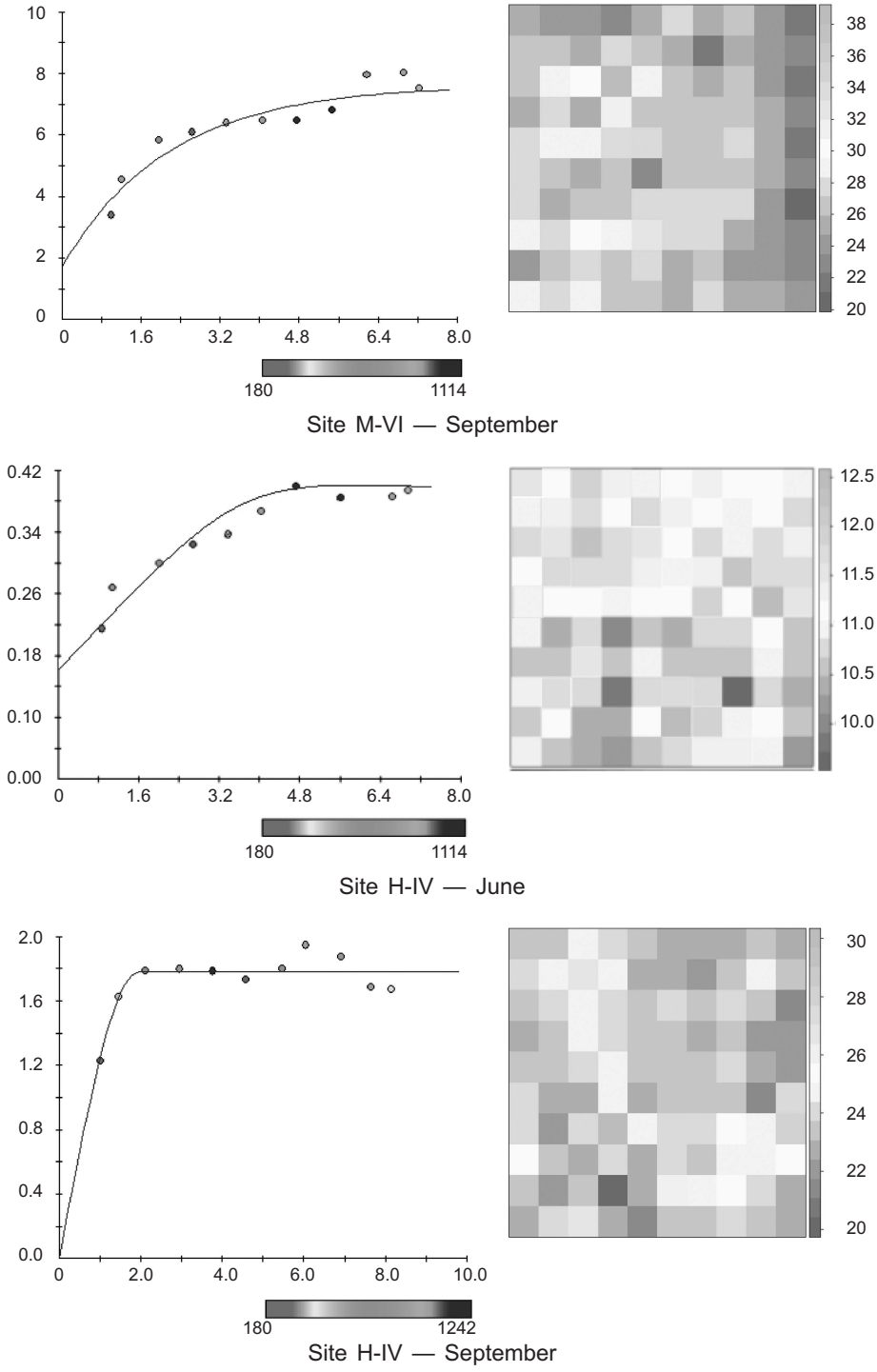


Fig. 62. Empirical variogram of the soil moisture and the fitted mathematical model together with mapping cont.

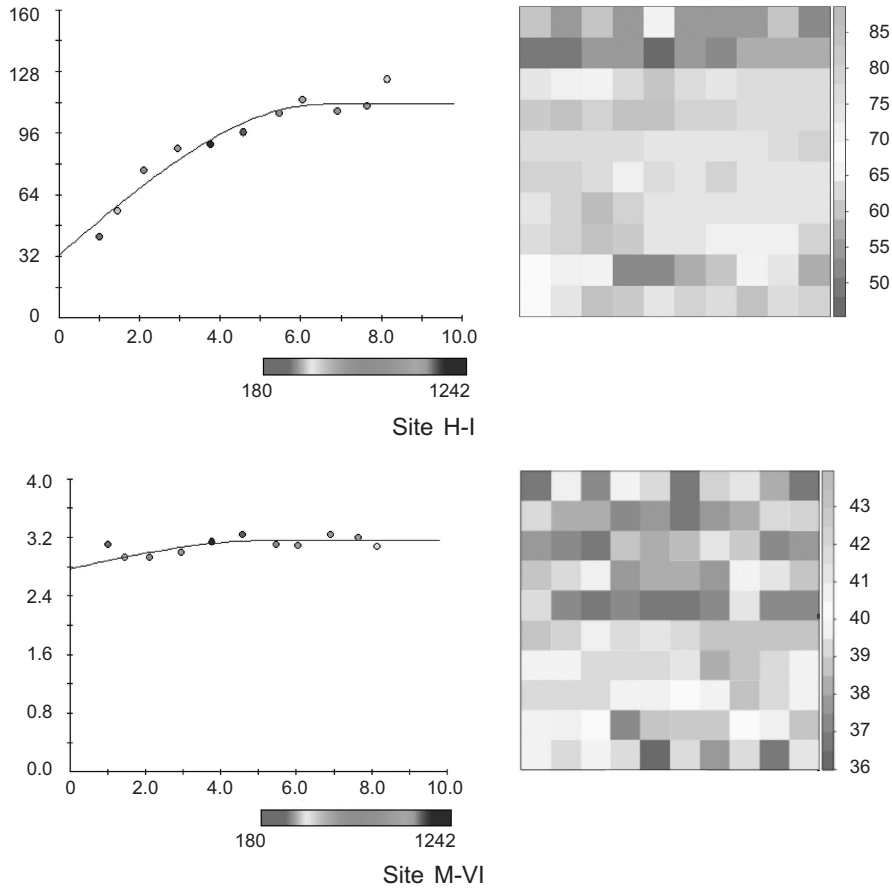


Fig. 63. Empirical variogram of the solar radiation intensity and the fitted mathematical model together with mapping

Table 20. Parameters of variograms for the variable soil moisture

Site	Model	Nugget	Sill	Range	RMSE	AIC
moisture in June						
H-I	Spherical	0.1109	0.2724	5.5	0.0133	–62.51
M-VI	Exponential	0	max	max	0.0034	–92.55
H-IV	Exponential	0.1910	0.3489	4.9	0.0266	–70.22
moisture in September						
H-I	Spherical	5.426	6550.9	max	2.8010	55.04
M-VI	Exponential	1.716	5.909	2.2	0.4355	14.09
H-IV	Spherical	0	1.884	1.9	0.0731	–25.19

Geostatistical analysis revealed the presence of a slight spatial trend at site H-I in September and M-VI in June, which is manifested in a constant increase of the variogram preventing the determination of a sill value. Higher heterogeneity of the plots in respect of the soil moisture was observed within the site H-I — the nugget effect. In the latter case, spatial variability of the described parameter is continuous (nugget — 0).

Geostatistical analysis revealed spatial autocorrelation of solar radiation intensity at both sites analysed. A larger range was observed at site M-VI (range at the level of ca. 6.5 m), together with higher diversity in values of solar radiation intensity (the effect of nugget).

Table 21. Parameters of variograms for the variable: solar radiation intensity

Site	Model	Nugget	Sill	Range	RMSE	AIC
solar radiation intensity						
H-I	Spherical	2.773	0.3877	5.3	0.0897	–20.68
M-VI	Spherical	32.680	78.400	6.6	5.9420	71.58

Envelopes of a variogram

Envelopes created for variograms are presented in Figures 64—66. Envelopes are marked with a dotted line.

In the case of the variable density of seedlings, no significant spatial autocorrelation was recorded at sites H-IV and H-V — the whole variogram is comprised within the "confidence" interval determined by envelopes.

In the case of the variable soil moisture content (soil substrate), no significant spatial autocorrelation was recorded at the site H-I September — the whole variogram is comprised within the "confidence interval" determined by envelopes.

In the case of the variable PPFD, no significant spatial autocorrelation was recorded at site M-VI — the whole variogram is comprised within the "confidence interval" determined by envelopes.

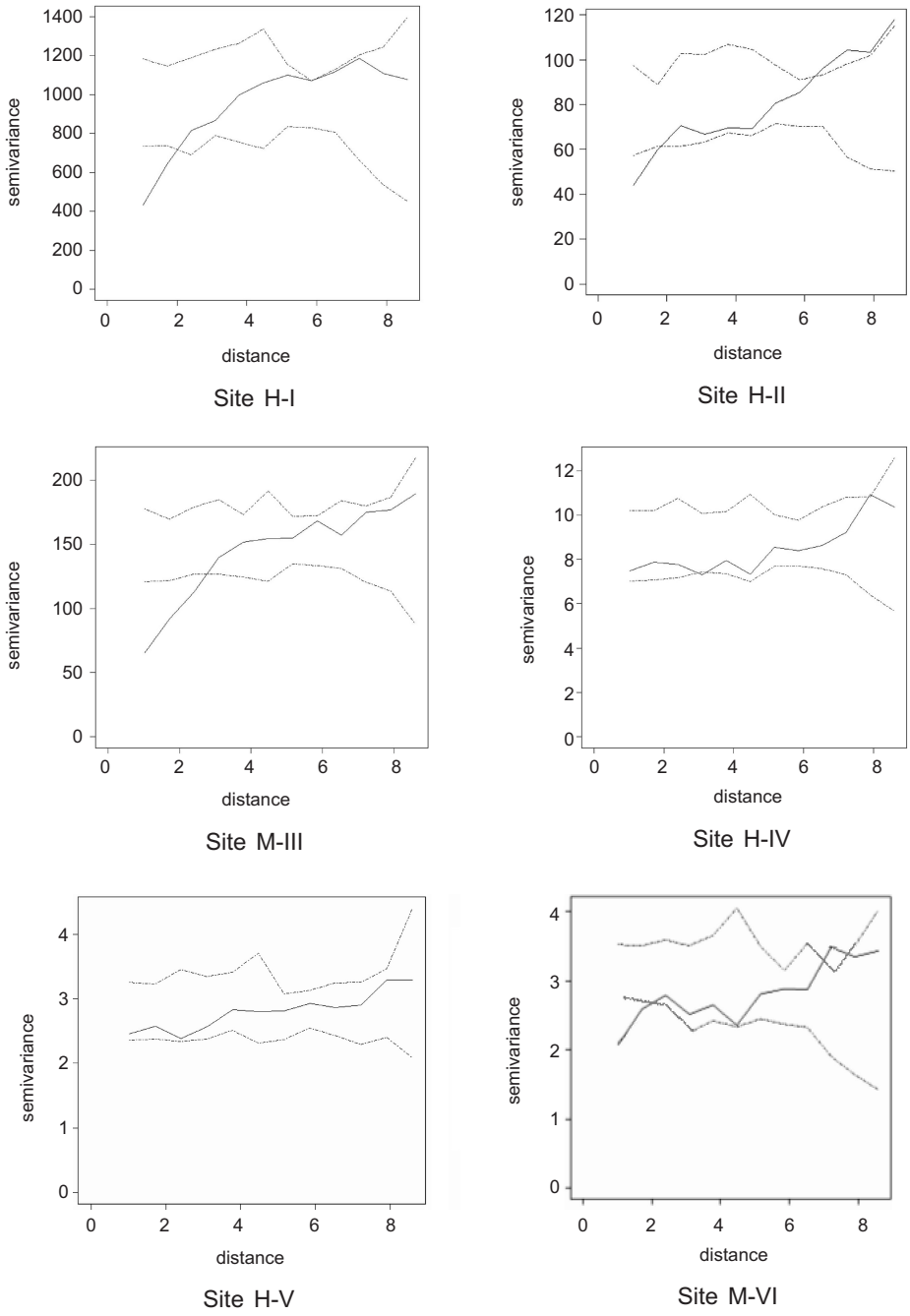


Fig. 64. Envelopes of variograms for the variable: density of seedlings

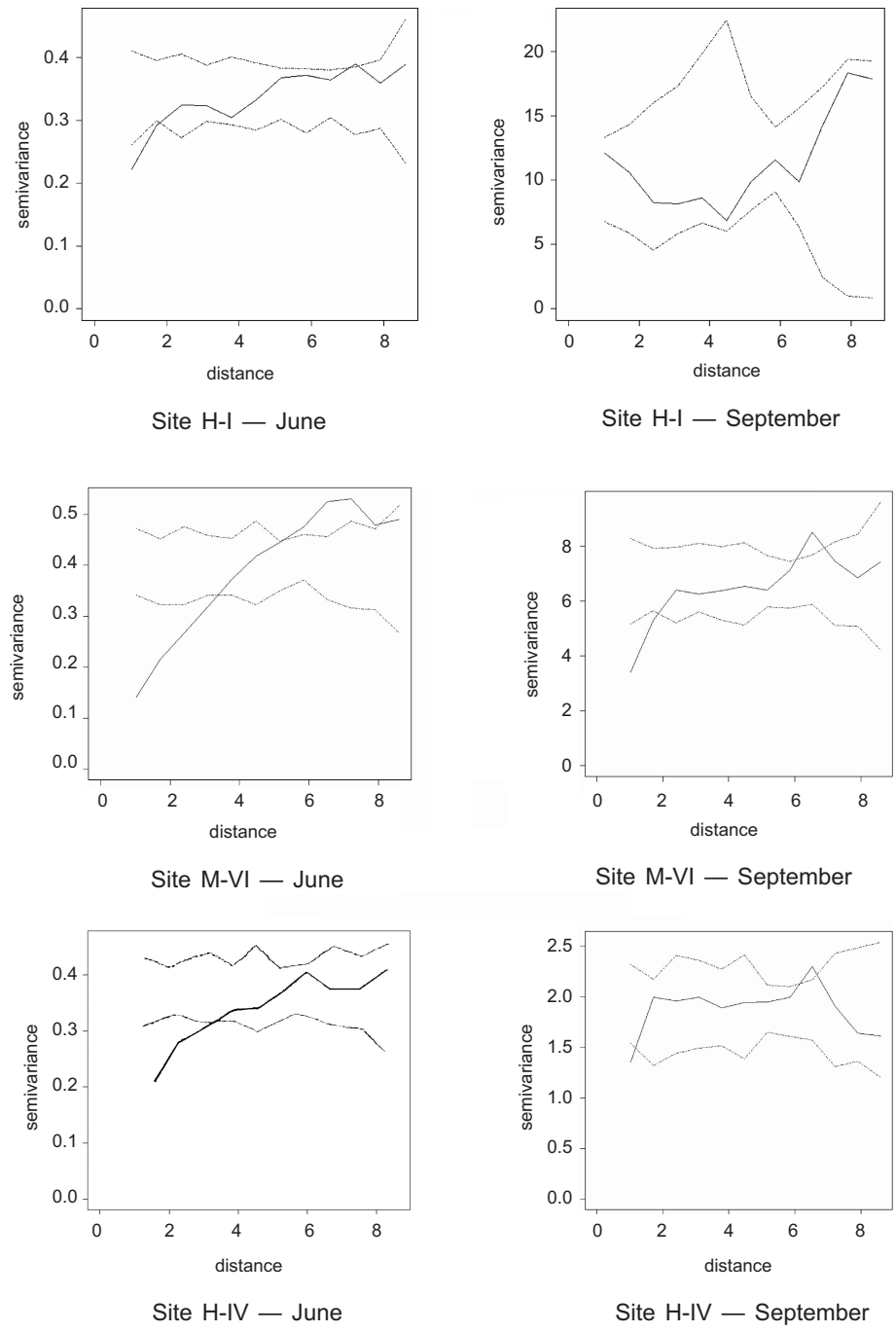


Fig. 65. Envelopes of variograms for the variable: moisture of the soil substratum

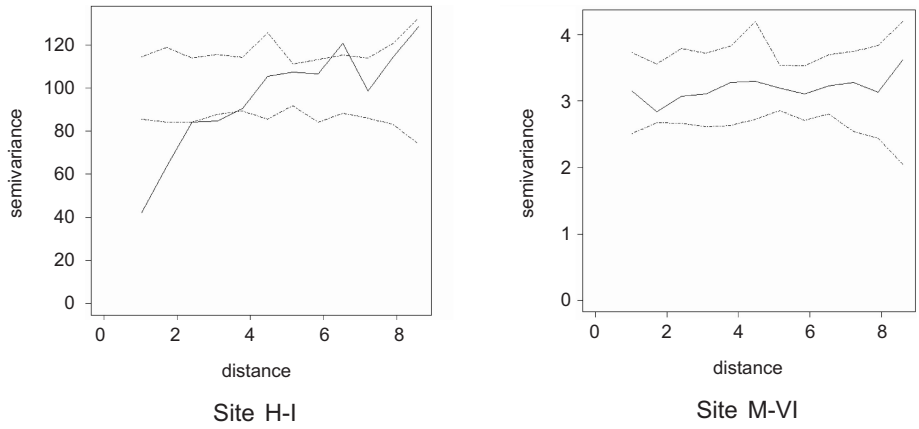


Fig. 66. Envelopes of variograms for the variable: PPFD

Statistical analysis of biometric parameters

Analysis of variance revealed significant differences for all the studied biometric characteristics. Tables 22 and 23 present the results of Tukey's test. When analysing the results for the parameter seedlings height, it was noticed that Tukey's test revealed statistically significant differences between the three research sites — H-I, H-IV, H-V — and the other sites (M-III, M-VI, H-II), in respect of the described parameter.

When analysing the parameter called the number of leaves, it was observed that Tukey's test revealed the presence of statistically significant differences between sites M-III and M-VI, as well as between sites from the older part of the dumping ground (H-IV, H-V) and those located in the younger part (H-I, H-II).

Table 22. Tukey's test for the parameter: seedlings height (significant differences with $p = 0.05$ are marked *)

Site	H-I	H-II	M-III	H-IV	H-V	M-VI
H-I		0.001*	0.001*	0.582	0.535	0.001*
H-II	0.001*		0.992	0.001*	0.001*	0.990
M-III	0.001*	0.992		0.001*	0.001*	0.861
H-IV	0.582	0.001*	0.001*		0.999	0.001*
H-V	0.535	0.001*	0.001*	0.999		0.001*
M-VI	0.001*	0.990	0.861	0.001*	0.001*	

Table 23. Tukey's test for the parameter: number of leaves (significant differences with $p = 0.05$ are marked *)

Site	H-I	H-II	M-III	H-IV	H-V	M-VI
H-I		0.264	0.001*	0.001*	0.001*	0.001*
H-II	0.264		0.001*	0.001*	0.001*	0.075
M-III	0.001*	0.001*		0.999	0.998	0.001*
H-IV	0.001*	0.001*	0.999		0.991	0.001*
H-V	0.001*	0.001*	0.998	0.991		0.001*
M-VI	0.001*	0.075	0.001*	0.001*	0.001*	

For the parameter defined as the number of branches, the result of the chi-square test amounts to 169.5 with $df = 1$ and $p = 0.000$, and indicates statistically significant differences in the number of branches between specimens growing in the relatively clean and specimens from the polluted area. It means that in the group of specimens growing in the clean area, the majority of specimens had more than one branch, whereas the group from the dumping ground was dominated by birch seedlings with 1 branch.

Part Six

Discussion

Influence of environmental stress-related factors on the content of photosynthetic pigments

Life processes of plants are influenced by numerous and changeable environmental factors. Variability of the environment, its spatial heterogeneity and diverse demands of plants during their lifetime determine the dynamic character of plant — environment relationships (Falińska 1990; Packham, Harding, Hilton 1994). Regularly recurring seasonal fluctuations in the level of environmental factors affecting the plants resulted in the development of unique adaptive traits. Irregularly occurring unfavourable factors bring about disturbances in several life processes. In such cases, the chances of survival are increased by maintenance of favourable energy balance by specimens, which is often connected with the growth inhibition and protection of cellular structures against deformation. Protection of these structures against injuries and, in extreme cases, even disintegration, determine the maintenance of homeostasis of the whole organism (Schuepp, Hendershot 1989; Silvola, Ahlholm 1995). In plants vulnerable to environmental stress-related factors, photosynthesis is one of the most sensitive physiological processes that determine their growth and development (Smith 1990; Bazzaz, Ackerly 1992).

Changes taking place in the structure and concentration of photosynthetic pigments in the photosynthetic apparatus are probable causes of photosynthesis inhibition at the molecular level (Combs, Hall 1982).

In this paper, the research covered the leaves of silver birch trees growing at four areas different from each other in respect of anthropopressure. It was found that changes taking place in the photosynthetic apparatus constitute a good indicator of influence exerted on plants by environmental stress-related factors. Literature data related to the content of photosynthetic pigments of deciduous trees reveal large

species differences in the values of these parameters. In the paper by Jakus (1985), the content of *chlorophyll a* in *Quercus cerris* in fully developed leaves ranges from 1.28 mg × kg^{-1} DW, in *Acer tataricum* 3.35 mg × kg^{-1} DW, and in *Cornus mas* 3.85 mg × kg^{-1} DW. The concentration of *chlorophyll b* amounted to 0.46 mg × kg^{-1} DW, 0.52 mg × kg^{-1} DW, 0.64 mg × kg^{-1} DW, respectively. In silver birch, the maximum concentration of *chlorophyll a* in leaves collected from the areas of the Białowieża National Park was 5.54 mg × kg^{-1} DW, and *chlorophyll b* 1.36 mg × kg^{-1} DW. (Przybylski, Ciepał, Palowski 1994). From the research by Valanne, Valanne, Niemi (1981), carried out on leaves of birch trees growing near Turku in Finland, it appears that the concentration of *chlorophyll a* and *b* was 0.22 mg × kg^{-1} FM (fresh leaf mass). According to Kauppi (1991), the total of chlorophylls determined in fully developed leaves of silver birch trees from Oulu in Finland was 2.71 mg × kg^{-1} FM. Inconsistent methods of data presentation constitute some difficulty when comparing the results obtained by different authors. In the literature, the following units of the chlorophyll content are encountered: mg × g^{-1} FM (Valanne, Valanne, Niemi 1981), mg × kg^{-1} DW (Przybylski, Ciepał, Palowski 1994), mg × leaf surface $unit^{-1}$ (Hendry, Grime 1993; Saebo, Krekling, Appelgren 1995), kg × t^{-1} (Oleksyn 1998).

Based on my own researches on the content of photosynthetic pigments in leaves of birch trees from four different research sites, it appears that the content of photosynthetic pigments in particular growing seasons is subject to large fluctuations. Variation of the results applies not only to differences in the concentration of pigments: from 0.35 mg × kg^{-1} DW to 1.77 mg × kg^{-1} DW for *chlorophyll a* and from 0.10 mg × kg^{-1} DW to 1.23 mg × kg^{-1} DW for *chlorophyll b*, but also to changes in the chlorophyll content in leaves when comparing the subsequent research years. In 2006, the lowest concentration of pigments *chlorophyll a* and *b* was recorded in leaves of birch trees growing on the slag heap, and in 2007 the opposite tendency occurred as compared with trees from other research areas. Fluctuations in the concentration of photosynthetic pigments are affected not only by changes in the weather, the exceptionally dry summer in 2007, but also by habitat changes. The slag and mine waste dumps are strongly disturbed habitats, characterized by large temperature fluctuations and soil at the initial stage with a low content of nutrients. These are open areas with highly permeable gravel or rocky substrate. Mirów and Łodygowice can be classified as stable habitats differing from each other in climatic conditions and the type of soil substrate.

The researches confirmed that biotic and abiotic stress-related factors influence the content of photosynthetic pigments. Water deficit is one of the factors affecting the content of photosynthetic pigments in the photosynthetic apparatus of plants. This is caused either by lack of available water in the substrate, or atmospheric drought, which often occurs in combination with high temperatures (Norby, Kozlowski 1981; Norby, Kozlowski 1982; Morse, Wayne, Miao 1993). This kind of situation frequently occurs in the area of both dumps, where the phenomenon of water deficit is connected not only with strong insolation but also with a highly water-permeable substrate, which intensifies this effect. During long-lasting

overheating not only the content of chlorophyll decreases, but also other processes occur that resemble the ageing of chloroplasts (Czarnowski 1987). In the conditions of increased temperature, disintegration of grains into individual thylakoids was frequently observed, which may result in changes of fluorescent light emission (Harding, Guikema, Paulsen 1990; Kozlowski, Kramer, Pallordy 1991; Li, Berlyn, Ashton 1996). This phenomenon can account for such huge differences in the concentration of *chlorophyll a* and *b* between the sites of the slag heap and the village of Mirów in 2007.

It appears from the performed research that in 2006 the concentrations of *chlorophyll a* and *b* in leaves of birch trees growing on the slag heap were the lowest as compared with other research sites. The reduced content of photosynthetic pigments is related to the fact that photosystem II in chloroplasts is the most sensitive to overheating, as well as to other types of stress, including water deficit (Kramer 1980; Ranney, Bir, Skroch 1991). Besides the chlorophyll, photosystem II contains over 20 different protein subunits, polypeptides, as well as manganese, copper and calcium (Wettstein, Gough, Kannangara 1995). During the thermal stress of leaf cells, this composite complex becomes partially dissociated. This is followed by a release of some polypeptides stabilizing the centre of water and manganese ions break-down, as well as formation of free radicals, which causes disintegration of chloroplast membranes (Sgherri, Pinzino, Navari-Izzo 1993). Large amounts of the superoxide radical, a factor responsible for destructive changes in the photosynthetic apparatus, are created when the excess of the absorbed luminous energy damages the photosystem I. Such disturbances can lead to oxidation of lipids and photosynthetic pigments, and in extreme cases — damage to proteins contained in membranes of thylakoids (Mikkelsen, Ro-Poulsen 1994; Starck, Chołuj, Niemyska 1995).

A considerable decrease in the concentration of photosynthetic pigments in silver birch leaves, obtained as a result of the performed analyses, compared to literature data with the same methods applied, can be explained by changes in the habitat abundance (Tsel`niker, Malkina 1994). For ions of nitrogen, potassium, phosphorus and magnesium play a key role in the efficient process of chlorophyll biosynthesis, as well as in the transportation and distribution of photoassimilates (Crabtree, Bazzaz 1993; Goransson 1994). In leaf cells, a large part of organic nitrogen is located in chloroplasts. Membranes of thylakoids contain from 1/4 to 1/5 of all nitrogen in leaves, and the deficiency of this chemical element results in changes of their functioning (Makino, Osmond 1991; Kull, Niinemets 1993). Then the ageing of chloroplasts accelerates, which consists in the destruction of the system of thylakoids, the occurrence of plastoglobules and considerable accumulation of starch therein. Inhibition of the synthesis of proteins and chlorophyll results in the development of chloroplasts with low photosynthetic efficiency (Hendry, Grime 1993).

Nitrogen deficiency intensifies the harmful influence of strong solar radiation on the photochemical capacity of PS II. Nitrogen together with magnesium constitutes the main structural component of a chlorophyll molecule. Magnesium is deemed as one of the most important coenzymes in particular stages of synthesis of this

pigment, and its deficiency results in a decrease of the chlorophyll content in leaves (Ericsson, Kahr 1995). With the potassium deficiency in a plant, inhibition of protein synthesis occurs together with a decrease in the activity of many enzymes involved in the metabolism of carbohydrates and the synthesis of starch. Low concentration of inorganic phosphorus restricts the transport of triose phosphates from the chloroplast to cytoplasm. They are then used for starch synthesis, whose concentration in the stroma can additionally inhibit the photosynthesis (Harrison, Miles, Howard 1988).

In the performed analyses on birch leaves in 2007 and 2008, the highest concentrations of carotenoids were recorded in trees growing on the slag heap, as compared with leaves of populations from other research sites. This phenomenon could result from the progressing chlorophyll breakdown proving the ageing of the photosynthetic apparatus, which is evidenced by the presence of other pigments, particularly carotenoids and xanthophylls. Wolińska (1975) distinguished three types of changes in carotenoids of ageing leaves. Depending on plant species, as well as habitat and climatic changes, these changes can occur before, simultaneously or after a decline in the chlorophyll content. In *Acer pseudoplatanus* carotenoids were disintegrated more slowly compared to chlorophyll loss, in *Quercus robur* — equally fast, and in *Pinus nigra* — a decrease in the content of carotenoids was much faster. At the same time, changes in the percentage contribution of particular carotenoids were observed to the advantage of xanthophylls.

In the results presented, no significant reduction of the ratio *chlorophyll a* to *b* was recorded. The ratio of the content of these pigments, which is the dimensionless quantity, ensures the comparison of results obtained by authors applying different methods for the presentation of the concentration of pigments. In fully developed leaves, the concentration of *chlorophyll a* is two times higher as compared to *chlorophyll b*. Compared with *chlorophyll b*, the chemical structure of *chlorophyll a* is more susceptible to changes of environmental factors. According to the theory by Siuta (1980), the ratio of the content of *chlorophyll a* to *b* under the influence of industrial contamination is reduced even up to the value of 1, whereas under the influence of stress factors, such as water deficit, the level of these pigments decreases evenly. As a consequence of this phenomenon, the value of the described ratio remains almost constant.

This theory can be proved by the results obtained in the present paper in 2006, where the ratio of *chlorophyll a* to *chlorophyll b* is constant for all research sites. In the successive growing seasons, values of the ratio of the two pigments are different. This phenomenon can be explained by the increased lability of pigments caused by stressful influence of photoinhibition, which takes place during atmospheric drought and the possibility of transforming the labile molecules of *chlorophyll a* into *chlorophyll b* (Woźny 1995).

Adaptation changes in the photosynthetic apparatus of silver birch

During the evolutionary development, each specimen of the population becomes adapted to specific environmental factors. In natural conditions, an organism is

usually influenced by a few correlated unfavourable ecological factors. The stress influencing a cell, a specimen or a whole population, destabilizes life processes at each of the individual organization levels (Thompson, Naeem 1996). The survival strategy of specimens consists in avoiding the stress or tolerating its consequences. The mobilisation of both groups of defensive mechanisms — avoiding and tolerating — is the measure of adaptation of specimens to stress conditions (Lange, Heber, Schulze 1989; Starck, Chołuj, Niemyska 1995; Modrzyński 1998; Starck 1998).

Adaptation of plants to unfavourable environmental conditions might be revealed in the form of phenotypic changes, often correlated with the resistance to other types of stress, such as: changes in radiation, drought, high temperature (Tripepi, George, Dumroese 1991; Stewart, Dwyer 1994a, b). It appears from the study by Kauppi, Kiviniitty, Ferm (1990) carried out on the birch that the mechanism of species tolerance of excessive insolation and overheating consists in changes of the location of chloroplasts in a cell. The light absorption by chloroplasts is then modified, and consequently also the intensity of photosynthesis. Also modifications in the system of thylakoids were observed, as well as in the shape of palisade mesophyll cells (Koski, Selkainaho 1982).

Differences in the composition of photosynthetic pigments can constitute another example of adaptation changes in the photosynthetic apparatus at the leaf level. These differences are related not only to chlorophyll quantitative changes, but also to accumulation of carotenoids with a protective function towards photosystems (Houpis, Surano, Cowles 1988; Mikkelsen, Dodell, Lutz 1995). Such changes were observed also in the present study, when analysing leaves of birch trees from two dumps.

In unfavourable climatic conditions and with the lack of sufficient amounts of nutrients reducing the photosynthesis, the distribution of photoassimilates is modified (Koike 1995). It is yet another adaptation mechanism at the specimen level consisting in the reduction of the lamina surface area (Tripepi, George, Dumroese 1991; Stewart, Dwyer 1994a). According to Henrykiewicz-Sudnik (1985), the surface area of a fully developed birch leaf comes to 10 cm^2. Similar results were obtained in the present study for populations of birch trees from Łodygowice, whereas a drastic reduction in the surface area of laminae was observed in the specimens growing on the slag heap. Changes in the distribution pattern of photoassimilates may influence the condition of the whole population. Generative organs of plants absorb larger amounts of photoassimilates compared with vegetative organs. In the conditions of long-lasting stress, first a decline in setting of fruits was observed, and then the growth inhibition of a whole plant (Barcikowski, Zbigniewicz 1992; Berntson, Farnsworth, Bazzaz 1995; Bonser Aarssen 1996).

Another mechanism related to adaptation changes in the photosynthetic apparatus of plants is described by Pell, Dann (1991) as a compensation cost of photosynthesis in the conditions of several ecological factors operating together. This phenomenon consists in the reduction of the activity of photoassimilates' acceptors, which results in the growth inhibition of a specimen, with its basic life functions

preserved. This phenomenon is confirmed by the results of my research on the photosynthetic apparatus of birch, where statistically significant negative correlations were obtained between the concentrations of all photosynthetic pigments and the surface area of leaves, only for the research sites located on the slag and mine waste dumps. From the correlation analysis performed, it appears that the growth inhibition of a lamina triggers off the compensation mechanisms of photosynthesis (the increase of chlorophyll concentration), which increases the survival chance of a specimen in strongly disturbed habitats.

Generative reproduction of silver birch and factors affecting reproduction success

The reproductive potential of plant organisms is genetically conditioned and depends on biological traits of a species. This not only describes the capacity of organisms to produce the progeny and their viability, but also the fertility of particular specimens at the reproductive stage. Plant populations accomplish their reproductive potential in specific ecological conditions. Individuals during their development are influenced by both abiotic factors and species interactions. And thus, on the one hand, reproduction of a population is accomplished by a species genetic program, and on the other hand, through external factors, i.e. it is induced by environmental conditions.

In the world of plants, seeds constitute the highest form of adaptation to species generative reproduction. The correct development of seeds is affected not only by the quality of the embryo sac and the quality of pollen, but also by climatic conditions during the pollen production (Fenner 1985; Hester, Gimingham, Miles 1991; Bradbeer 1998). My own researches carried out on the pollen viability on the nutrient agar in the laboratory conditions revealed that its germination power was significantly reduced — by 70—80% — in the area of both dumps, compared to other research sites. The influence of stress factors on the quality of pollen is confirmed by microscopic observations on the development of birch flowers carried out by Neuvonen, Nyyssonen, Ranta (1991) and Weis, Hermanutz (1993). Researches of these authors revealed that pollen is a structure sensitive to many environmental factors, e.g. acid precipitation and UV radiation. Also habitat factors, such as habitat richness, indirectly influence the process of formation and development of pollen grains (Houle 1992). According to research by Holm (1994c), the number and the quality of birch seeds influence the abundance of pollen production. Birch is one of those tree species which set seeds well only when the number of pollen grains on the stigma is higher than the number of ovules. According to Rodkiewicz (1996), the population effect could be the cause behind this phenomenon, which consists in the fact that a dense group of pollen grains in vitro germinate more effectively than pollen grains scattered one by one. Often a few pollen grains on a stigma germinate

less effectively than pollen grains in higher concentration. Six is the optimal number of pollen grains for birch to pollinate effectively (Dahl, Fredrikson 1996; Rodkiewicz 1996).

If the stigma receives many pollen grains, competition between pollen tubes may occur and then — as it is thought — more viable seeds are set, from which seedlings of a better quality develop (Seiwa, Kikuzawa 1996). A germinating pollen grain and its pollen tube release into a pistil certain substances with high physiological activity, which as activators, trigger off an additional physiological polarization of generative organs and acceleration of the embryo sack development (Zaufal 1993; Pasonen, Pulkkinen, Kärkkäinen 2002). Thus, both the quality and the amount of pollen influence the setting of seeds. These observations are confirmed by the results of my research, where the smallest number of staminate inflorescences was recorded in trees growing on the slag heap, together with the largest number of empty birch nuts. A different situation occurred in birch trees from the mine waste dump. A large number of staminate inflorescences guaranteed the abundance of pollen grains, and at the same time their optimal number on flowers' stigmata. At the same time, the viability of pollen and the ability of seeds to germinate was significantly reduced, compared with pollen and seeds from the research site located in Łodygowice. Perhaps, an interrupted barrier of self-sterility is the underlying cause of this phenomenon. In stressful conditions, flowers are pollinated with their own pollen and then parthenocarpic seeds develop (Paganova 1993). The extent of the developmental depression related to inbreeding is diverse, but usually seeds capable of further development are created. Apart from external conditions (the weather in a given year, or in a preceding year), the fruiting of birch trees is influenced by the availability of energy resources accumulated by a tree. Changes in the climatic and edaphic conditions induce modifications in the chemical composition of seeds and their physiological characteristics. Consequently, diaspores with different dormancy time are produced, even in the same fruit. The time of seed dispersal, particularly the time of seed germination is no less important than the place from which a young organism starts (Kulman 1984a). Most of the pioneer plants, including also birch, finish their reproductive cycle before an unfavourable season begins, i.e. winter. Germination in such conditions would in advance eliminate the chance of seedlings for their survival. In pioneer species, biochemical or physiological mechanisms develop, preventing the premature germination of seeds, or differentiating the duration of their dormancy. Birch seeds contain inhibitors whose effect consists in increasing the demands of an embryo for oxygen, the access to which is impeded by seed coats. On the other hand, the inflow of oxygen into the seeds can contribute to inactivation of an inhibitor through oxidation (Suszka 1979).

However, in the disturbed habitats with conditions changing in an unpredictable way, different maturation time for seeds even coming from the same fruit, is a quite common phenomenon. Consequently seeds germinate not simultaneously and thus increase the chance of successful progeny development. Most of the mature birch nuts are dispersed by wind at the end of summer. Some of the birch nuts, however,

may remain on a tree until winter and fall on the snow cover, and this can have significant ecological effects. Desiccation of seeds hanging on a tree can bring about the state of induced deep dormancy and can increase the time required for their germination by a few years. Falling of birch nuts on the snow facilitates their translocation by wind on the snow surface, often over long distances, much longer than in the case of seeds falling in autumn (Hughes, Fahey 1988). Diaspores moved by wind over the snow surface gather in large numbers in sheltered places favourable to germination. The small weight of nuts, a flight apparatus and at the same time, a large number of diaspores, provide the nuts with a chance to be placed in a site safe for germination in extreme habitats (Maillete 1982; Hughes, Fahey 1988; Matlack 1989). According to some authors, small diaspores more easily penetrate into the soil and create the so-called seed bank, which is a durable accumulation of alive seeds, potentially capable of germination (Pirożnikow 1983; Veino, Komulainen, Neuvonen 1993). The seed bank in combination with a large number of propagation units constitutes the basis for having progeny in the conditions of rather unstable environment. Polymorphism of birch seeds, examined in terms of the dormancy period duration, depending on habitat conditions is reflected in the sowing quality of seeds and the dynamics of their germination (Peterson, Facelli 1992). Seeds of birch trees from the slag heap were characterized by the lowest germination capacity — from 10.40% to 21.60%, as well as by the highest Pieper coefficient amounting to more than one day, compared to seeds coming from other research sites. The higher the Pieper coefficient, the slower the germination. The decreasing germination rate of seeds, as well as the reduced percentage of germinated seeds in a sample are certainly physiological symptoms of the decreasing viability of seeds. An immature seed embryo or influence of inhibitors might be the underlying causes of the reduced sowing value of seeds. This statement could be evidenced by a shift in the phase of the maximum germination of seeds from 4 to 6 days for diaspores coming from the slag heap. The low quality of seeds results from the influence of extreme habitat conditions exerted on parental organisms and on the course of the reproductive phase.

Research carried out on the number of seeds in fructifications of birch trees revealed that this value is a species trait. It was observed during particular research years that the number of birch nuts coming from trees growing in undisturbed areas is a more stable value. The largest number of birch nuts per fructification was recorded in trees from Łodygowice — 504 pieces, and this value is comparable with literature data, where the average number of birch nuts was 460 pieces (Atkinson 1992). In birch trees from the slag heap, the number of diaspores per fructification was 223. A decreased fertility of an individual caused by the absence of a suitable amount of resources is reflected not only in the reduced number of pistillate inflorescences, but consequently in the number of fructifications. In unfavourable growth conditions, often a different allocation of resources takes place: first of all the number of seeds drops in a fructification, therefore the number of the latter decreases less drastically. Naturally this happens at the expense of a reduced pool of resources, which potentially could be allocated for the increased seed production.

Flexible allocation of resources between fructifications and seeds is an important characteristic of adaptation to changeable environmental conditions, which affects the reproductive success of the species. The reduced number of seeds in a fructification, and not the number of fructifications, results from the selection of a plant exposed to the pressure of an herbivore. According to Holm (1993; 1994a), many seeds are destroyed by *Oligotrophus betulae*. When destroying a specific number of fructifications, animals eat fewer seeds if they are located in more numerous fructifications. The theory saying that in the stressful conditions plants produce the largest possible quantity of seeds within the available pool of resources, does not apply to birch. This strategy with limited resources would inevitably lead to a reduction of the seed size, which is already small.

Plasticity of plants is reflected in the diversified biomass of specimens. On the other hand, this characteristic indirectly or directly influences the population processes, including the reproduction (Safford, Czapowskyj 1986; Taylor, Davies 1986; Safford 1990). Plant organisms have a chance to survive and produce offspring all the more, the more biomass they accumulate. The production of offspring is in fact connected with the specific contribution of energy in the process of individual propagation. Together with the development of an individual, the accumulation of assimilation products is subject to considerable changes and they are accumulated in different proportions in particular underground and aboveground parts (Bazzaz, Miao, Wayne 1993). Because the biomass of a specimen determines the reproductive potential, and thus when and how often in a life cycle a given specimen allocates the energy for propagation. The higher the biomass of a specimen, the more energy it can allocate for propagation processes (Falińska 1991).

This statement is indirectly evidenced by the results of my own research, where birch trees growing in Łodygowice and Mirów developed the largest number of leaves — 412 and 511 pieces per branch — as compared to other research sites. Moreover, for birch trees from Łodygowice also the largest number of pistillate inflorescences was recorded — 54, as well as the longest staminate inflorescences — 3.21 cm and the longest axes of fructifications — 4.42 cm.

The survival strategy of plants in a given habitat can be considered as allocation of the energy and matters for three basic life processes: survival (maintenance) in the environment, the growth and development, as well as propagation — as a specific compromise between these three processes (Ericsson 1995). In each type of strategy, the priority is given to maintenance costs (Lehtila, Tuomi, Sulkinoja 1994; Messier Puttonen 1995). Investment in the development of pistillate flowers, and then in the development of diaspores entails the necessity of using a considerable part of energy resources of a given individual. Expenditure on the production of staminate flowers is significantly lower as compared to all expenditure involved in the female reproductive function. The number of produced flowers is in fact affected not only by atmospheric factors during their development, but also by the efficiency of internal transport of nutrients (Gunthardt-Goerg, Matyssek, Scheidegger 1993). In pioneer plants, two mechanisms controlling the allocation of energy resources of a specimen can be observed: for the growth and

the development. The first mechanism occurs in therophytes whose vegetative growth becomes completely inhibited and plants gradually switch to reproduction processes. Whereas the second mechanism applies to perennial plants, where initiation of the generative phase is conditioned by sufficiently high biomass of vegetative plant parts and gradual transition from one stage to another. This phenomenon is accompanied by a considerable reduction of the growth intensity during the period of full flowering and fruiting (Stewart, Dwyer 1994a, b). This statement is confirmed by the results of correlation analysis performed in my own researches. They describe statistically significant negative correlations between the number of pistillate and staminate inflorescences and the number of leaves and their surface area for birch trees growing in the villages of Mirów and Łodygowice. This could prove that individuals allocate a larger part of energy expenditures for generative reproduction than for the development of vegetative parts. At the same time, the amount of resources allocated by an individual for the production and the development of full birch nuts is not regular. Analysis of the results obtained in the present study describes the statistically significant positive correlation between the length of pistillate inflorescences and the number of full birch nuts in a fructification for birch trees from the village of Mirów, and the inverse correlation for the same parameter for birch trees growing in the village of Łodygowice. It is noteworthy that pistillate inflorescences reached the maximum length in birch trees from Mirów, and the minimum length in trees from Łodygowice.

The analysis of individual components of the final reproduction effect indicates their immense flexibility, while reactions of plants to unfavourable factors, leading to low reproduction efficiency, are not always comprehensible. It is difficult, however, to consider the reproductive behaviour of individuals of any species, and in particular pioneer plants, such as birch, separately from a general life strategy. Grime's concept of life strategies does not include species adapted to strong stress and intensive disturbances at the same time. However, great capabilities of preserving the occupied territory through a shallow but extensive root system, and capabilities of tolerating the nutritional deficiency, low moisture content, high temperatures ensure the development of birch populations in stress-inducing habitats and vulnerable to disturbances (Pratt 1986; Ranney, Bir, Skroch, 1991; Ranney, Whitman 1995).

Learning about life strategies and reproductive tactics of plant populations, facilitates more profound understanding of factors determining the adaptation of populations. Identification of one, two or three factors would always be a simplification. One cannot, in fact, assume that one of the them is the only mechanism controlling the adaptation, perhaps it is a factor inducing or stimulating other mechanisms.

Influence of the selected habitat factors (moisture, solar radiation intensity) on the shape of spatial structure of seedlings

The area of Upper Silesia is one of the areas in Poland where anthropogenic transformations of the environment are most strongly reflected in the landscape. The effect of the intensive economic activity is a considerable transformation of the land surface and high contribution of devastated post-exploitation areas (Rostański 2006). The post-industrial dumps, due to dusting, chemical and thermal activity, as well as contamination of subterranean waters and surface watercourses, are objects troublesome for the surroundings, particularly for areas devoid of the vegetation cover. Accumulation of substantial amounts of post-industrial waste materials, difficult to dispose of, constitutes an important problem in the Upper Silesian Industrial District. Among the most troublesome objects are dumping grounds, which were created as a consequence of mining of non-ferrous metal ores and production of metals: lead and zinc. Dumping grounds for zinc and lead tailings, due to toxicity caused by high concentration of heavy metals, as well as the lack of nutrients and the humus soil layer, are areas particularly difficult to restore (Skubała 2011).

Encroachment of vegetation on this type of wasteland depends on several habitat factors, mainly soil properties, for example: reaction of the substrate, soil structure and the content of nutrients. Also the type of waste dumping techniques is important (a type of industrial process and waste disposal). In the case of zinc-containing waste dumping grounds, the concentrations of heavy metals in the substrate, in quantities that are toxic for the development of plants, is an additional factor limiting the development of vegetation.

In such extreme conditions, only plants with special properties can grow, develop and form long-lasting vegetation cover. Those species were classified by Grime (1979) as resistant to stress (S). The studied European white birch (*Betula pendula* Roth, which plays a significant role in the process of succession, has characteristics attributed to strategy S (high seed production), as well as to strategy C, because it is characterized by high competitive abilities. Birch is a typical pioneer species. It is highly photophilous and is characterized by fast growth, as well as by wide amplitude in relation to most of the ecological factors. The species described is resistant to slight frost and low temperature during winter, and is not particularly sensitive to drought during summer.

According to Falińska (1996), successful colonization by a plant in extreme conditions is determined mainly by a reproduction strategy, and thus by high seed production. Birch is an anemochorous species. It produces large quantities of light seeds, which are easily carried by wind over considerable distances (Suszka, Muller, Bonnet-Masimbert 2000). And thus, anemochory is one of the most important properties of the birch, which is the first species to encroach into the habitats of

post-industrial dumping grounds. This property combined with genetic flexibility, enables colonization and existence of birch on pioneer anthropogenic habitats.

The conducted research revealed great heterogeneity of the studied sites in respect of the number of occurring seedlings. These differences concern both the dumping ground (the heap/dump), and the areas relatively free of post-industrial contamination.

The largest number of seedlings was recorded at the research site H-I (1669 seedlings within 10 m^2), where the most unfavourable habitat conditions prevailed, as compared to other sites analysed. Apart from toxicity of the substrate, the following factors inhibit the growth and the development of vegetation: the lack of vegetation cover, strong solar radiation (PPFD twice as high as compared to natural conditions) and low moisture content in the soil substrate (average moisture — ca. 7.5% with almost 15% in "clean" area). In the situation when there are several factors operating, potentially responsible for the mortality of seedlings, high density of seedlings is the only way to ensure the recruitment of new specimens. High reproduction capacity of birch (the number of seedlings) on the initial dumps (site H-I) is probably a response to a considerable mortality rate of juvenile stages.

Perhaps the emergence of birch seedlings and their maintenance in difficult habitat conditions, which prevail at the site discussed, results from high adaptability. As an example Falińska (1996) quotes researches by Fabiszewski, Brej, Bielecki (1986), who imply areas that the success of plants in colonization of bare areas, devoid of vegetation and heavily polluted, depends on encroachment of new diaspores resistant to contamination. The species *B. pendula* (diploid; $2n = 28$) is characterized by very high gene flow and the occurrence of spontaneous intraspecific and interspecific hybrids, diversified in respect of many ontogenetic traits. Therefore, one can assume that as a result of very strong pressure exerted by the environment of the heap and the exceptional flexibility of the species *B. pendula*, a local adaptation of birch to conditions prevailing on the heap develops, as well as an ecotype with fixed traits.

In the case of plants that function in difficult habitat conditions, and in particular in post-industrial areas with a high level of contamination with heavy metals, the phenomenon of mycorrhiza is of particular significance (Rostański 2006; Gucwa-Przepióra, Turnau 2001). Mycorrhiza can easily colonize initial sites of succession. As quoted in numerous scientific papers, there are following effects of favourable influence exerted by mycorrhiza on plants: the increased resistance of plants to salinity, as well as to the presence of heavy metals and changes in substrate pH (Antosiewicz 1992; Gucwa-Przepióra, Turnau 2001; Skubała 2011).

Many laboratory experiments carried out at the Tennessee University (USA) prove that mycorrhized oak seedlings maintained turgor during drought for a longer time as compared to control plants. The same research revealed also that mycorrhiza can increase the resistance of plants to low or high temperature. Seedlings of a pine species (*Pinus taeda*) mycorrhized with strains of a fungus tolerant of high temperature, survived without any damage for 5 weeks at a temperature of +38°C, while most of the control plants died. Seedlings of the Eastern white pine (Weymouth pine) cultivated in containers in the substrate with fungi brought from

the region of natural occurrence of this tree, turned out to be much more resistant to low temperature. As much as 80% of them overwintered in an unheated greenhouse, whereas only 20% of seedlings cultivated in the sterile substrate survived the winter (Zak 1973; Antosiewicz 1992; Gucwa-Przepióra, Turnau 2001). In view of the quoted research, one can assume that in the conditions prevailing on the dump, i.e. with the lack of water and most of the nutrients, as well as with the increased content of heavy metals and very strong insolation, the phenomenon of mycorrhiza can be of vital significance, facilitating the colonization of peculiar types of habitats, such as post-industrial dumps.

Based on the research conducted, it was found that the count of seedlings at the other three research sites, selected within the zinc-containing waste dump ZM "Silesia", was much lower. These differences are probably connected with the presence of vegetation cover at these sites. For many species it was observed that the dense cover of graminaceous plants is a factor limiting the emergence and the survival rate of seedlings (Platt 1975; Peart 1989a, b, c). Probably, the competitiveness of meadow plants is also the cause behind the small number of seedlings recorded at site M-VI.

Kwiatkowska, Simonides (1980) and others believe that most plant species are characterized by the clumped pattern of spatial distribution. Nieckuła (1987) and Falińska (1990) report that the clumped type of spatial distribution usually depends on the habitat heterogeneity and characteristics of a taxon.

Properties of the spatial structure (the *range* value) interpreted from the shape of variograms, together with data mapping, point to clumped spatial distribution of seedlings, while the size of these clumps fluctuated from ca. 2 (site M-VI) to 7 metres (site H-V).

For several reasons, which determine the universality of the clumped structure, the soil substrate structure comes to the fore. It has been repeatedly demonstrated that miscellaneous depressions and other dislocations on the soil surface can significantly influence the recruitment of seedlings, because seeds find there favourable conditions for survival in the state of "dormancy" and "a safe place for germination" (Harper 1980). Variability in the soil substrate structure usually brings about a correlated pattern of soil moisture distribution, which affects the plasticity and oxygenation, while these factors determine the rooting capabilities of seedlings and the growth of plants (Krebs 2011). Rostański (2006) reports that on post-industrial dumping grounds, water availability or water deficit are the main factors determining the development of spontaneous vegetation cover.

Application of geostatistical analysis in this study ensured the comparison of spatial structure of seedlings within a single research plot, as well as the comparison of selected habitat factors: humidity of the soil substrate and solar radiation intensity (PPFD).

In the case of site H-I, it was found that both density of seedlings and spatial variability of the soil substrate humidity had a clumped pattern. In both cases, the range of spatial autocorrelation (the size of clumps) was identical (*range* = 5.5 m). The research proved that spatial variability in the density of seedlings in the exposed

place (the average value of solar radiation intensity at the site discussed amounts to ca. 70 μmol $m^2 \times s^{-1}$) is largely connected with fluctuations in the soil substrate humidity. In the case of site M-VI, where seedlings also tended to form clumps (*range* 2.2 m), their spatial distribution seems to be independent both from changes in the soil moisture and from solar radiation intensity. For the geostatistical analysis revealed that diversification of the soil moisture in June was very small within the site analysed (no *nugget* effect), which means that spatial changes in the humidity were proceeding gradually. On the other hand, characteristics of the spatial structure interpreted from the shape of variograms for the parameter: intensity of solar radiation indicates that spatial variability in PPFD was very high and random (clear contribution of *nugget* in the structure of variograms). Geostatistical analysis revealed that only soil moisture in September had a tendency to form clumps (the *range* value = 1.9); visualization of the variable, however, also excludes the participation of this factor in the determination of the variability of the studied seedlings.

Site M-VI comprised the meadow area, which has not been exploited since decades and was located at a certain distance from forest. Based on long-term researches carried out on permanent research plots (Falińska 2002), it is known that in an unexploited meadow, owing to a rapid development of clonal plants, the structure of meadow communities becomes less dense and new niches develop. Specimens of some species reach their full growth only after cessation of mowing; then they expand and reach their maximum height. The subsequent sudden or gradual change in quantitative and spatial relationships between populations of meadow species results in the disturbance of the vegetation cover. The developing gaps can be colonized by species other than those present during the exploitation of the meadow. And thus, perhaps loosening of the structure of the meadow community and the development of gaps is a sufficient reason accounting for the formation of clumps of birch seedlings.

In the case of sites located in the older dumping ground (research sites H-IV and H-V), the geostatistical analysis for the variable density of seedlings indicates high contribution of *nugget* in the structure of variograms, which implies that the spatial density pattern for seedlings is random here. At one of the aforementioned sites (H-IV), the soil moisture content was measured and the obtained data were analysed (geostatistical analysis). After the comparison of variograms, influence of the studied factor on the development of spatial variability of seedlings could be excluded. Despite the existence of the clear gradient of the soil moisture content, the pattern of seedlings' density seems to be independent of the latter. Perhaps the smaller number and the spatial structure of seedlings are connected with the presence of dense grassy vegetation cover (mainly *Calamagrostis epigejos* (L.) Roth), whose roots develop in more shallow layers of the soil substrate and thus can constitute a factor limiting the emergence and the survival of seedlings.

In the ecological literature dedicated to issues of spontaneous succession (Rostański 2006) on post-industrial waste dumping grounds, one can often find a statement that high variability of habitat conditions prevails even within one

object. Examination of the soil moisture content carried out in different parts of the heap (sites H-I and H-IV), as well as at different times, are in line with this opinion. One can assume that diversification in the moisture content between the studied sites is associated with the state (density) of the vegetation cover, which is a significant parameter differentiating the studied sites. At site H-IV located within the older part of the dumping ground, dense vegetation cover inhibits the surface water runoff and reduces its drying up. At site H-I, precipitation quickly flow down through the soil substrate devoid of vegetation cover, and dark colour of the deposited material, strongly accumulating the heat, additionally intensifies the loss of water.

When analysing the volumetric water content at particular research sites, one can observe that the presented average values in June are half of those recorded in September. Diversification of the moisture results can be affected by the amount and the intensity of precipitation in the period preceding the collection of samples. According to data of the Meteorological and Hydrological Institute in the city of Katowice for the years 2009 and 2010, in June, i.e. at the time of sample collection and in May, i.e. one month before the research, the total precipitation was lower (7.5%) as compared to precipitation recorded in September and August.

Perhaps this interesting phenomenon, observed at all research sites, is also connected with the developmental phase of vegetation (i.e. root water uptake intensity). In June — in the period of intensive developmental processes, the demand of plants for water increases. Plants using the water resources contained in the substrate increase its deficit.

Based on the analyses performed, it was found that high variability of the soil moisture content is not only quantitative, but also spatial. Large changes in the soil moisture probably result from high heterogeneity of the soil substrate.

Characteristics of biometric parameters of specimens growing in different parts of the post-industrial dumping ground and in the area relatively free of post-industrial contamination

The size of specimens is one very plastic trait and is a recognized measure of populations' life conditions (Andrzejewski and Falińska 1986). The size and the habit of plants depend on the habitat abundance, hydrographic and light conditions, the absence or presence of competitors, as well as the density of specimens. According to Falińska (1990), unfavourable environmental conditions may be the cause of poor development of specimens. The results of the present study confirm the aforementioned opinions.

Biometric studies of the above-ground shoots revealed diversification of specimens from the heap and from the area free of post-industrial contamination (Mirów). The most significant differences concern the height of shoots and the number of branches. Birch trees growing in the conditions of strong anthropopressure were characterized by a smaller number of branches and three times smaller height, as compared to birch trees growing in the relatively clean area. This considerable variation in values of biometric parameters, describing the morphological traits of specimens, is probably associated with different moisture and light conditions. The soil of Mirów area is characterized by higher moisture content and low light availability as compared to the dump substrate. On the dry substrate, there is an increase in the contribution of biomass stored in the underground parts of a seedling in relation to biomass of a specimen, which causes the lower height of seedlings.

It is believed that worse biometric parameters of birch growing on the zinc-containing waste dumping ground result from the influence of anthropogenic factors. The detailed soil examination carried out in the dumping ground revealed that the content of heavy metals, i.e. lead and cadmium, was considerably exceeded. *B. pendula* is listed among species of outstanding capabilities to accumulate chemical elements, such as Pb, Zn, Cd (Franiel 1996). Plants accumulating heavy metals are usually characterized by high tolerance (Daves 1992). Authors of the earlier papers report that a significant characteristic of many plant populations tolerant to metals is their weaker growth, as compared with plants from uncontaminated soils (Ernst, Schat, Verkleij 1990; Lefebvre, Vernet 1990). This phenomenon is often explained as energy costs for mechanisms of tolerance to metals (Wierzbicka 2002).

The results obtained and the analyses carried out revealed that site H-II, which covers the area of latest dumping, differs statistically significantly from other sites regarding the parameter defined as height. As indicated by fairly frequent reports (Rostański 2006; Carnation 1993; Wierzbicka 2002), the soil substrate exerts a significant influence on the development of plants, and consequently on the processes of colonization and succession on post-industrial waste dumping grounds. Based on the observations performed and photographic documentation, one can state that the sites located in the younger part of the dumping ground, are heterogeneous in respect of particle size distribution. At site H-II, where average values for the height of birch specimens are higher, the deposited material is characterized by the increased contribution of fine-grained fractions. Perhaps better habitat conditions and the lack of competition from grassy vegetation are the reasons for better biometric parameters of birch trees growing at this site.

Interesting results were obtained for the parameter defined as the number of leaves. For instance, it was observed that the sites relatively free of industrial contamination (M-III and M-VI) statistically significantly differ in respect of the aforementioned parameter. At site M-III located directly by the forest, shoots are characterized by the number of leaves three times smaller as compared to specimens growing at a greater distance from the forest M-VI.

This type of reaction could constitute a response of birch to high population density (14 specimens per 1 m^2). As a consequence of high density, seedlings must reach the highest possible height in order to shade other specimens and win the competition for light. One could assume that the trade-offs rule works here — specimens reach their height at the expense of considerable reduction of leaves. The results obtained are in line with the opinion expressed by Falińska (1998). Based on the research, the author stated that the biomass and the number of specimens depend not only on the abundance of a habitat in nutrients, but mainly on the presence or absence of other species competing with each other for space and food. As emphasized by Falińska (1996), the significance of competition is not the same throughout the life cycle of a specimen, and usually is the highest at the seedling stage.

Part Seven

Conclusions

In the author's opinion, the most important conclusions of this study area are as follows:

- Specimens of birch growing at four areas, different from each other in respect of anthropopressure, did not develop a universal reproductive strategy.
- Setting of seeds in a birch population is affected not only by the quality of pollen, whose viability in the disturbed habitats is considerably reduced, but also by the amount of pollen.
- Reproduction capacity of a birch population is conditioned by the production of seeds and their germination capacity, and indirectly by environmental conditions.
- In the disturbed habitats, a reduced percentage of germinated seeds and the decreasing germination rate prove their low sowing value.
- In the disturbed habitats, a species responds to stress by ageing of the photosynthetic apparatus, as well as by the reduction of the number of leaves and their surface area.
- Clumped structure is most often encountered among the seedlings studied. Moisture of the soil substrate is the factor that most strongly influences the clumped structure on the initial dumps; in the natural conditions, the appearance and the recruitment of new specimens are conditioned by the presence of gaps in the vegetation cover.
- The smaller count and random spatial distribution of seedlings on the restored dumps are connected with dense, grassy vegetation cover.
- During colonization of a specific area by a plant, a number of biotic and abiotic factors operate simultaneously, determining the abundance and the spatial structure. Geostatistical analysis is a useful exploratory tool which helps search for key factors affecting the spatial variability of plants. With the application of geostatistical software, one can obtain consistent fitting of theoretical models — variograms — to empirical data, therefore conclusions drawn on the basis of

variograms regarding the spatial structure of the phenomena studied can be considered as well-founded (even without a significance level quoted), and the estimated patterns — as reliable.

- The observed diversification of biometric characteristics of specimens occurring in different parts of the dumping ground, result from different habitat conditions prevailing within the object studied.
- It was found that a specific habitat of anthropogenic origin had a considerable impact on characteristics of biometric parameters of silver birch seedlings. *Betula pendula* differs in biometric characteristics from plants occurring on “clean” soils. Further research is necessary in order to decide whether these traits are only a phenotypic reaction as a response to adverse and specific conditions prevailing on the calamine dump, or some genotypic changes had already developed.

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Izabella Franiel

Biologia i ekologia *Betula pendula* Roth na zwałowiskach poprzemysłowych: modyfikacja cech *life history*

Streszczenie

Zdolność organizmu do reprodukcji jest gwarancją trwałości istnienia gatunku. Na skuteczność propagacji mają wpływ przede wszystkim płodność osobnicza oraz żywotność potomstwa, aż do osiągnięcia fazy reprodukcji. Rozwój roślinności na otwartych przestrzeniach nieużytków poprzemysłowych jest ciągle procesem słabo poznanym. Warto więc przyjrzeć się, jak kształtuje się zmienność przestrzenna wkraczającej na te tereny roślinności, a także na ile warunki bytowania oraz cechy osobników znajdują odzwierciedlenie w ich organizacji przestrzennej. Kompleksowe badanie zmienności przestrzennej roślin i uwzględnienie w badaniach jednocześnie wielu zmiennych stało się możliwe ze względu na zaadaptowanie do przestrzennej analizy zmienności danych metody geostatystycznej.

Celem badań była ocena właściwości populacji *B. pendula* rosnącej w warunkach zróżnicowanej antropopresji z uwagi na: wybrane cechy *life history* (np.: parametry wielkości, biomasy osobników, ocena płodności osobników), określenie kondycji osobników brzozy, ocenę czynników abiotycznych i biotycznych odpowiedzialnych za rozmieszczenie siewek w przestrzeni. Do badań wybrano brzozę brodawkowatą — gatunek siedliskotwórczy o szerokiej skali ekologicznej, odporny na zanieczyszczenia środowiska. Badania prowadzone były w latach 2005—2008 i 2009—2010 na 4 powierzchniach badawczych, różniących się stopniem antropopresji. Doświadczenie podzielono na dwie części: terenową i laboratoryjną. W części terenowej liczbę liści brzozy, ich powierzchnię oraz zawartość barwników asymilacyjnych określono w czasie pełnego rozwoju liści. Cechy biometryczne kwiatostanów oraz owocostanów brzozy oznaczono na początku i na końcu sezonu wegetacyjnego. W części laboratoryjnej wykonano badanie żywotności pyłku oraz wartości siewnej nasion. Aby zbadać, jak kształtuje się zmienność przestrzenna siewek brzozy brodawkowatej oraz jakie czynniki wpływają na ich wzorce przestrzenne, wyznaczono 6 poletek badawczych w obrębie 2 kontrastujących pod względem stopnia presji antropogenicznej powierzchni badawczych.

Analiza wyników badań poszczególnych elementów składających się na ostateczny efekt reprodukcji wskazuje na ich ogromną plastyczność, przy czym reakcje rośliny na czynniki niekorzystne, prowadzące do niskiej efektywności rozrodu, nie zawsze są zrozumiałe. Poznawanie strategii życia i taktyki reprodukcyjnej populacji roślinnych umożliwia pełniejsze poznanie czynników warunkujących przystosowanie populacji. Wyróżnienie jednego, dwóch czy

trzech czynników będzie zawsze pewnym uproszczeniem. Nie można bowiem założyć, że jeden z nich jest jedynym mechanizmem sterującym adaptacją; być może jest on czynnikiem włączającym lub stymulującym inne mechanizmy.

Najczęściej spotykaną strukturą badanych siewek jest struktura skupiskowa. Na zwałach inicjalnych czynnikiem najsilniej wpływającym na strukturę skupiskową jest wilgotność substratu glebowego; w warunkach naturalnych pojaw i rekrutacja nowych osobników uzależnione są od obecności luk w pokrywie roślinnej.

Stwierdzono wyraźny wpływ specyficznego siedliska pochodzenia antropogenicznego na cechy parametrów biometrycznych siewek brzozy brodawkowatej. Cechy biometryczne brzozy brodawkowatej różnią się od cech biometrycznych roślin występujących na glebach niezanieczyszczonych. Wskazuje się na potrzebę dalszych badań, aby stwierdzić, czy cechy te są tylko reakcją fenotypową, następującą w odpowiedzi na trudne i specyficzne warunki panujące na hałdzie galmanowej, czy też doszło już do zmian genotypowych.

Wyniki prezentowanej pracy mogą stanowić nowe źródło wiedzy na temat sposobu kształtowania się pokrywy roślinnej, która zasiedla zdegradowane tereny nieużytków poprzemysłowych. Tylko rezultaty długoterminowych badań nad procesami zasiedlania przez poszczególne gatunki zwałów poprzemysłowych mogą ułatwić prace planistyczne związane z rekultywacją i zagospodarowaniem takich obiektów.

Izabella Franiel

Biologie und Ökologie der Spezies *Betula pendula* Roth auf postindustriellen Kipphalden: Modifikation von *life history* Mermalen

Z u s a m m e n f a s s u n g

Die Vermehrungsfähigkeit des Organismus sichert die Lebensdauer der Spezies. Die Effektivität der Ausbreitung wird vor allem von individueller Fruchtbarkeit und von Lebenskraft der Nachkommenschaft, bis zum Erreichen der Vermehrungsphase, beeinflusst. Die Entwicklung der Pflanzen auf offenen Gebieten des postindustriellen Ödlandes ist immer noch kaum erforscht, deshalb wollte die Verfasserin untersuchen, wie sich die solche Gebiete besetzenden Pflanzen räumlich ausbreiten und inwiefern sich die Lebensbedingungen und ihre individuellen Eigenschaften in räumlicher Anordnung der Pflanzen widerspiegeln. Sie konnte die räumliche Veränderlichkeit der Pflanzen ganzheitlich erforschen und in ihren Forschungen mehrere Variablen gleichzeitig anwenden, denn sie hat die mittels geostatischer Methode verschafften Daten an räumliche Analyse angepasst.

Das Ziel der Forschungen war, die Eigenschaften der Population von der in unterschiedlichen anthropogenen Verhältnissen wachsenden Birke *Betula pendula* in Anbetracht: ausgewählter Merkmale der *life history* (z.B.: Größe, Biomasse, Fruchtbarkeit der Individuen) zu beurteilen; die Kondition von den einzelnen Individuen der Birke einzuschätzen; die für die räumliche Verteilung der Sämlinge verantwortlichen abiotischen und biotischen Faktoren zu bewerten. Zu Forschungen wurde die Warzenbirke gewählt, eine biotopbildende Spezies mit weitreichender ökologischer Skala, die gegen Umweltverschmutzung unempfindlich ist. Die Forschungen wurden in den Jahren 2005—2008 und 2009—2010 auf vier mehr oder weniger anthropogenen Versuchsflächen durchgeführt. Der Versuch bestand aus Feld- und Laborforschungen. Im Rahmen der Feldforschungen wurde die Anzahl der vollentwickelten Birkenblätter, deren Fläche und der Gehalt von Assimilationsfarbstoffen beurteilt. Biometrische Eigenschaften von Blütenständen und Fruchtständen wurden zu Beginn und zu Ende der Vegetationszeit bezeichnet. Die Laboruntersuchungen sollten die Vitalität des Blütenstaubs und die Saatfähigkeit der Samen bestimmen. Zu diesem Zwecke wurden 6 Versuchsgelände im Bereich von zwei hinsichtlich des anthropogenen Drucks zueinander in Kontrast stehenden Versuchsflächen abgesteckt.

Die Analyse der Forschungsergebnisse von den einzelnen, für das Endeffekt zusammenlegenden Elementen deutet auf deren große Anpassungsfähigkeit hin, aber die Reaktion der Pflanze auf ungünstige, eine niedrige Vermehrungseffizienz mit sich bringende Faktoren ist

nicht immer klar. Die Erkundungen über Lebensstrategie und Vermehrungstaktik von Pflanzenpopulationen lassen, die eine Anpassung der Population begünstigenden Faktoren besser erkennen. Die Hervorhebung von einem oder mehreren Faktoren wird immer eine Vereinfachung bedeuten. Man kann zwar nicht voraussetzen, dass nur einer von ihnen imstande ist, die Anpassung zu steuern; er ist vielleicht ein solcher Faktor, der andere Mechanismen einbeziehen oder anregen kann.

Unter den untersuchten Sämlingen tritt am häufigsten die Anhäufungsstruktur auf. Auf Initialkippen wird die Anhäufungsstruktur von der Feuchtigkeit des Bodensubstrates am stärksten beeinflusst; in natürlichen Verhältnissen sind das Erscheinen und die Beschaffung von neuen Individuen von den Lücken in der Vegetationsdecke abhängig.

Es wurde festgestellt, dass der spezifische anthropogene Biotop einen deutlichen Einfluss auf biometrische Parameter der Sämlinge von der Warzenbirke hat. *Betula pendula* unterscheidet sich von den auf unverschmutzten Böden wachsenden Pflanzen in biometrischen Merkmalen. Die Verfasserin zeigt auf, dass es nötig ist, weitere Forschungen durchzuführen, um feststellen zu können, ob diese Merkmale lediglich eine phänotypische Reaktion sind, die eine Antwort auf schwierige und spezifische auf einer Zinkspatkippe herrschende Bedingungen ist, oder es sind schon eher genotypische Differenzierungen entstanden worden.

Die in vorliegender Arbeit dargestellten Forschungsergebnisse können ein richtiger Born des Wissens sein über die Art und Weise, auf welche die Vegetationsdecke auf dem postindustriellen unfruchtbaren Ödland entsteht. Nur die Ergebnisse der langdauernden Forschungen über die Besiedelung der postindustriellen Kipphald von den einzelnen Spezies können bei den mit der Rekultivierung und mit dem Bewirtschaften der Gebiete verbundenen Planungsarbeiten helfen.

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